The Journal of

THE ROYAL AERONAUTICAL SOCIETY

CONTENTS NOVEMBER 1949

...TH THE BRITISH COMMONWEALTH AND EMPIRE
... LECTURE—INTER-CITY TRANSPORT DEVELOP-
...MENT ON THE COMMONWEALTH ROUTES
E. D. ATKIN, B.Sc., F.R.Ae.S.

...HE DESIGN OF COMPRESSION STRUCTURES FOR
...MINIMUM WEIGHT
D. J. LAIRD, M.A., A.F.R.Ae.S.

...OTES ON THE OPENING BEHAVIOUR AND THE
... OPENING FORCES OF PARACHUTES
R. H. HAYA, M.A.

...RAFT DEFECT REPORT PROCEDURE
A. C. GREENWOOD, A.F.R.Ae.S.

...EVIEWS

...ORRESPONDENCE

DOWTY
Liquid Spring
main and nose
UNDERCARRIAGES
(with power steering)
are fitted to the
BRISTOL BRABAZON
DOWTY EQUIPMENT LIMITED, CHELTENHAM

At ease in the Hermes **The chairs for the Handley Page Hermes were specially built by Vickers-Armstrongs to B.O.A.C. specification. No more comfortable or flexible aircraft chair has ever been designed. For the passenger there is instant finger-tip control of an infinite variety of positions ensuring the utmost comfort throughout his journey. For the aircraft constructor the chair incorporates great strength consistent with its low weight of 37 lbs. The Hermes chair is one of 24 types built by the Vickers-Armstrongs team that designed the chairs fitted in the Vickers Viking, the Short Solent, the Canadair Four and many other well-known aircraft. Vickers-Armstrongs will design and supply chairs for any airliner, transport, bomber or fighter.**

VICKERS-ARMSTRONGS LIMITED AIRCRAFT DIVISION, WEYBRIDGE WORKS, WEYBRIDGE, SURREY
AT65

Choose

YOUR HOLIDAY PLACE

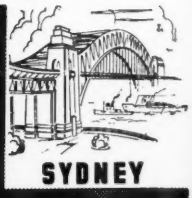
Travel without trouble by Australia's International Airline—famous for 28 years of service. On the ground and in the air, Qantas makes your personal comfort a paramount responsibility.

Ask your travel agent for details.

Come abroad to see the World!

SINGAPORE

ROME


SYDNEY

NORFOLK Is.

NEW GUINEA

CAIRO

INDIA

LORD HOWE Is.

NOUMEA

SUVA

PAKISTAN

Fly there

WITH

QANTAS EMPIRE AIRWAYS
Australia's International Airline

Q·E·A

IN ASSOCIATION WITH BRITISH OVERSEAS AIRWAYS CORPORATION

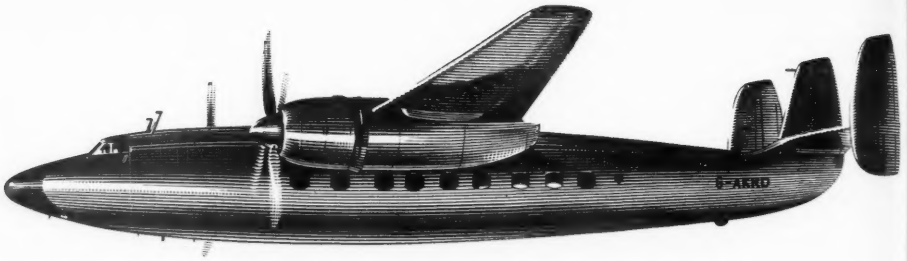
WORLD-WIDE AUTHORITIES ... *ON DESIGN, OPERATION & PRODUCTION OF ALL TYPES OF AIRCRAFT*

FLIGHT (weekly) provides the most authentic information on world aeronautical affairs. It covers every aspect of development and progress in aircraft and power unit design and operation. AIRCRAFT PRODUCTION (monthly) is the journal of the aircraft manufacturing industry, specialising in tools and works production processes. The editorial staffs of each journal are experts in their own particular sphere, with unrivalled experience and resources. Both journals serve the interests of all concerned with the future progress of British Aviation. Technical information is supplemented by brilliant functional drawings Circulation is world-wide. Annual subscriptions (Home and Overseas) FLIGHT £3.1.0, AIRCRAFT PRODUCTION £1.14.6.

Published in conjunction with these journals. FLIGHT HANDBOOK (212 pages, 7/6 net) is essentially a manual for the student, whilst GAS TURBINES AND JET PROPULSION (272 pages, 12/6 net) by G. Geoffrey Smith, has been widely adopted as the standard textbook on the subject by Universities, Technical Institutions and Training Centres everywhere.

ASSOCIATED ILIFFE PUBLICATIONS

DORSET HOUSE, STAMFORD STREET, LONDON, S.E.1. WATERLOO 3333 (60 LINES)



Commercial Efficiency

It is doubtful whether any other civil aircraft has an economical payload/range performance to equal that of the Ambassador.

Carrying a payload of more than 11,000 lb. the Ambassador's ultimate range is 850 miles when cruising at 280 m.p.h. For this speed the power used is 2,760 b.h.p., and the consumption is 1·65 miles per gallon.

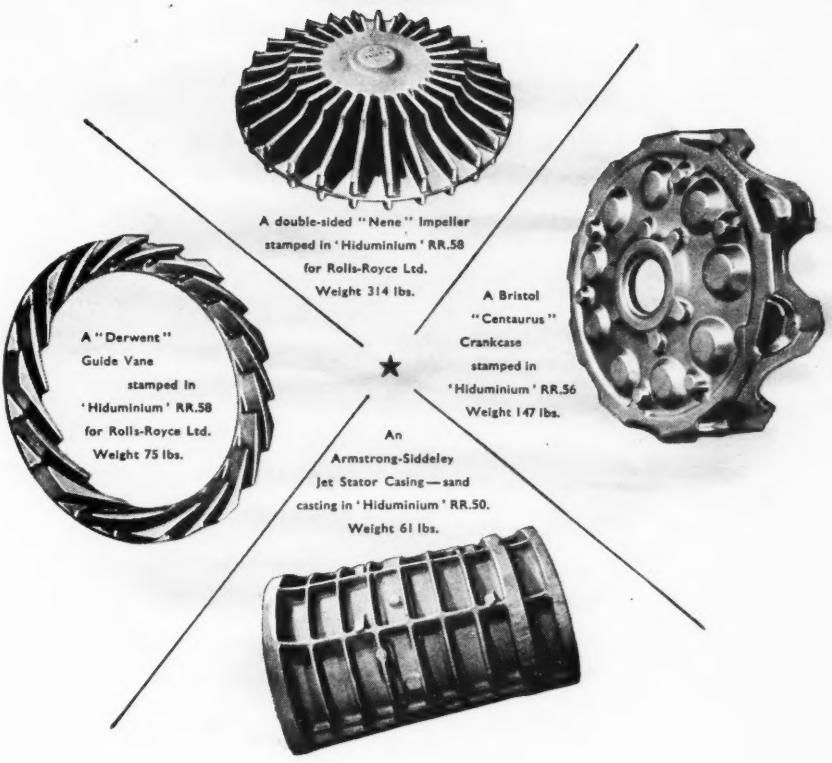
In terms of operating efficiency, the Ambassador can be flown over 500/600-mile stage distances for a direct operating cost of 1½d per passenger-mile.

AMBASSADOR

AIRSPEED LIMITED

CHRISTCHURCH AND PORTSMOUTH, ENGLAND

In association with the de Havilland Enterprise


A double-sided "Nene" Impeller stamped in 'Hiduminium' RR.58 for Rolls-Royce Ltd. Weight 314 lbs.
A "Derwent" Guide Vane stamped in 'Hiduminium' RR.58 for Rolls-Royce Ltd. Weight 75 lbs.
A Bristol "Centaurus" Crankcase stamped in 'Hiduminium' RR.56 Weight 147 lbs.
An Armstrong-Siddeley Jet Stator Casing—sand casting in 'Hiduminium' RR.50. Weight 61 lbs.

Wherever British aircraft take the air they rely to a greater or lesser degree upon components supplied by High Duty Alloys. Illustrated here are four typical examples of how the Aircraft Industry

... makes light work of it with **HIGH DUTY ALLOYS**

HIGH DUTY ALLOYS LIMITED, SLOUGH, BUCKS. INGOT, BILLETS, FORGINGS, CASTINGS & EXTRUSIONS IN 'HIDUMINIUM' & 'MAGNUMINIUM' ALUMINIUM & MAGNESIUM ALLOYS
(Registered Trade Marks)

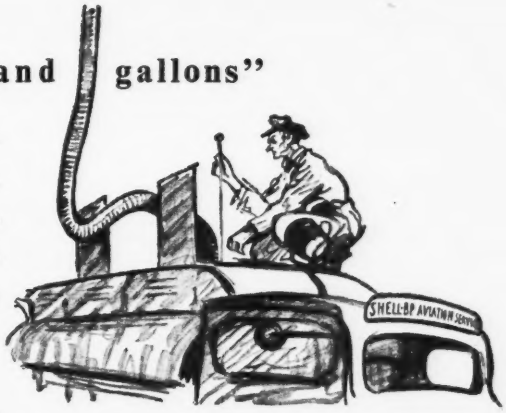
MESSIER

HYDRAULIC ACCUMULATOR

The Messier type of cylindrical accumulator with separator piston is a highly refined design of extreme simplicity. Lighter than competitive designs including spherical types, it is available in a full range of capacities for two standard pressures — 2500 and 4000 lb. sq. in.

BRITISH MESSIER LIMITED CHELTENHAM ROAD EAST GLOUCESTER TELEPHONE CHURCHDOWN 1[illegible]

"Two thousand gallons"



"That's what this tanker is taking aboard — 2,000 gallons at about 200 gallons a minute. You've got to have speed, flexibility. The next aircraft we service may be parked for refuelling 2½ miles away. The captain may not give us long; but we see he gets away on time."

The Shell-BP Aviation Service has several crews and tankers at each chief British Airport. They are on duty every hour of the day and night, the whole year round. They fuel the aircraft of 24 International airlines — and countless charter companies. Shell and B.P. products are available at over 70 aerodromes throughout the country.

Shell-BP Aviation Service

Shell-Mex and B.P. Ltd., Shell-Mex House, Strand, W.C.2. *Distributors in the U.K. for the Shell and Anglo-Iranian Groups.*

DATA SHEETS

on

AERODYNAMICS and STRESSED SKIN STRUCTURES

For Use in Aeronautical Design
and
Drawing Offices

Write for full particulars to:—

The Secretary
THE ROYAL AERONAUTICAL SOCIETY
4 Hamilton Place, London, W.1. Grosvenor 3515

Britain's largest Landplane

THE "BRABAZON"
is fitted with and relies on "EATONIA"
water-cooled Phosphor Bronze Bushes

Y.E.S. Ltd
PHOSPHOR BRONZE & GUNMETAL
Bearings & Bushes

Sole Producers and Suppliers
YORKSHIRE ENGINEERING SUPPLIES LIMITED
"EATONIA" BRONZE FOUNDRIES LEEDS 12
Telephones: 38234-38291 Telegrams: "Yes, Leeds 12"

THE AERONAUTICAL QUARTERLY

Volume I NOVEMBER 1949 Part III

CONTENTS

Surging of Axial Compressors — *H. Pearson* and *T. Bowmer*

Strain Measurement by X-Ray Diffraction Methods — *G. B. Greenough*

Buckling of a Longitudinally Stiffened Flat Panel — *H. L. Cox* and *J. R. Riddell*

Approximate Calculation of the Laminar Boundary Layer — *B. Thwaites*

LONDON
ROYAL AERONAUTICAL SOCIETY
4 HAMILTON PLACE W1

10/-

Pitman Books

Parker Street · Kingsway · London, W2

Aircraft Engines of the World, 1949

By PAUL H. WILKINSON. This famous Annual has no equal for accurate, up-to-date information on the world's aircraft engines. This year the jet engines and gas turbines section is still further enlarged and now contains 40 complete standardized specifications of main power plants, with full-page illustrations. The reciprocating engine section is as comprehensive as ever. All concerned with engines should have this splendid illustrated reference work. Fully indexed. 50/- net.

The Factory

By DR. G. SCHLESINGER. All production engineers, works managers and industrial executives should study this important work. It is by one of the best-known international consultants on production engineering, and forms a complete guide to modern methods of equipping, organizing and bringing into production every type of factory. 300 large pages. 153 illustrations. 70/- net.

Strength of Materials

By F. V. WARNOCK, M.Sc., Ph.D., F.R.C.Sc.I., M.I.Mech.E. A textbook covering the syllabuses of the B.Sc.(Eng.), I.Mech.E., Inst.C.E., and the Advanced National Certificate examinations in this subject. Seventh Edition. 15/- net.

Permanent Magnets

By F. G. SPREADBURY, A.M.Inst.B.E. A comprehensive work by an authority. It deals fully with materials, including several only recently developed, and with design problems, etc. Profusely illustrated. 35/- net.

for Aeronautical Engineers

Fifth British Commonwealth and Empire Lecture

INTER-CITY TRANSPORT DEVELOPMENT ON THE COMMONWEALTH ROUTES

by

E. H. ATKIN, B.Sc., F.R.Ae.S.

The Fifth British Commonwealth and Empire Lecture was given before the Royal Aeronautical Society by Mr. E. H. Atkin, B.Sc., F.R.Ae.S., on the 15th September 1949 in the Lecture Hall of the Institution of Civil Engineers, Great George Street, S.W.1. Sir John Buchanan, C.B.E., F.R.Ae.S., President of the Society, presided.

The President: Following the Second Aeronautical Conference in New York earlier this year, with Captain Pritchard and Dr. Leggett, he had paid a visit to the branches of the Society in Canada, where they had received a warm welcome and great hospitality. They had visited A. V. Roe, Canada, Ltd., where the lecturer, Mr. Atkin, was Chief Designer, Airframe Design Division, and had been much impressed by the young and energetic staff that had been gathered together there.

A year or so ago he had also visited branches of the Society in Australia and New Zealand, and had been much impressed by the Society's high reputation overseas. It was such that the Council had under consideration the inauguration of reciprocal lectures, by members of the Society, to be delivered in the Dominions. At the moment the principal obstacle was that of ways and means.

He had much pleasure in introducing the Fifth British Commonwealth and Empire Lecturer. Mr. Atkin had taken his degree at London University and had served an apprenticeship with Edgar Allen & Co. Ltd., Sheffield, and Vickers, Ltd., at Barrow. From 1928-1930 he served as Draughtsman and Technical Assistant with Boulton Paul Aircraft Ltd., and then went to A. V. Roe & Co. Ltd., for four years as Senior Technical Assistant. In 1934 he rejoined Boulton Paul Aircraft Ltd., serving as Assistant Chief of the Stress Office until 1935, then as Chief of the Stress Office, and Chief Technician, and from 1937 to 1939 as Chief Engineer.

In 1939 he had returned to A. V. Roe & Co. Ltd., and had served as Assistant Chief Designer until 1946, when he went to A. V. Roe, Canada, Ltd., in charge of all design of new aircraft at the Canadian factory. His official title was Chief Designer, Airframe Design Division, A. V. Roe, Canada, Ltd.

He was a man of great experience, well qualified to speak on the subject he had chosen for his lecture.

IT was significant, I think, that, on the occasion of the British Commonwealth and Empire Lecture last year, Dr. Roxbee Cox was able to announce the formation of the Royal Aeronautical Societies of Australia and New Zealand as autonomous divisions, and the furtherance of the Society's activities elsewhere. Because of the widely separated centres of aeronautical activity in Ottawa, Toronto, Montreal, and elsewhere it has proved impracticable for the time being to form a Royal Aeronautical Society of

Canada. This does not mean that Canada is lagging in aeronautical activity, in fact the position is rather the contrary. It can safely be said that the growth of aeronautical activity has been greater in Canada than in any other part of the Commonwealth and Empire. Indeed many members of the Society in Canada feel they remain more closely knit to the parent body because of their direct affiliation. This is increasingly so because of the growing interchange of visits to both sides of the Atlantic with resulting stimulus to all concerned.

I am deeply conscious of the honour which the Society has bestowed upon me in inviting me to present the British Commonwealth and Empire Lecture for 1949.

I feel myself, however, most unfortunate in that I must follow the monumental monograph which Mr. Peter G. Masefield[2] presented last year.

It seems that for some years to come lecturers will perforce have to preach, so to speak, from a suitable text in the lecture of 1948.

Not having such resources at my command, I thought that in the space now permitted I might elaborate somewhat on the specialised, but important, section of air transport activity which may be described as inter-city transport.

I hope I shall succeed in some small way in furthering the mutual exchange which the Commonwealth Lectures foster and that this paper will be complementary in some respects to that of Mr. J. T. Bain,[1] who so ably and forcefully gave the operator's point of view in the 1947 lecture.

1. INTRODUCTION

From an aircraft and traffic point of view air transport appears now to be broadly divided into four categories:—

(*i*) Feeder Line Operation

(*ii*) Short Range or Inter-City Operation

(*iii*) Medium Range Operation

(*iv*) Long Range Operation.

These are fairly closely defined in terms of stage distance as follows:—

(*i*) Feeder Line Operation—up to, say, 250 miles

AIR TRAFFIC STATISTICS FOR CANADA AND U.S.A.

CANADIAN	Domestic		Chartered	International		Foreign	
1947	Pass.-miles	Ton-miles	Trans.	Pass.-miles	Ton-miles	Pass.-miles	Ton-miles
January	11,781,168	159,970	63,069	1,799,283	8,228	879,540	5,272
February	10,497,180	146,103	55,265	1,874,843	8,676	725,832	5,795
March		*Not available*					
April	15,872,978	340,025	195,094	3,211,192	12,305	1,131,246	9,089
May	16,333,209	192,600	23,561	3,185,778	9,639	1,109,501	8,791
June	19,510,434	194,149	22,306	3,360,603	9,026	1,275,918	7,877
July	19,929,466	205,341	59,441	3,872,177	10,618	1,626,614	7,510
August	20,841,747	199,007	64,868	4,713,416	11,302	1,971,431	8,178
September	19,863,682	286,524	65,178	4,039,416	9,641	1,891,739	12,115
October	18,890,424	266,243	62,858	3,247,565	10,620	1,495,281	12,416
November	14,786,749	171,459	18,851	2,396,815	7,438	907,674	14,742
December	14,947,577	216,744	34,130	2,189,442	6,604	852,851	11,168
	183,254,614	2,378,165	664,621	33,890,530	104,097	13,867,627	102,953
1948							
June	32,036,401	578,666	87,690	4,671,919	29,727	1,431,786	24,799
August	29,577,401	327,330	67,110	5,248,042	18,865	1,566,692	32,419
October	25,352,444	280,197	53,059	4,491,538	31,971	1,296,190	42,035

UNITED STATES	Domestic		International & Foreign	
January-October			January-September	
1948	5,024,536,000	109,454,591	1,412,360,000	41,599,214
1947	5,227,565,000	76,587,556	1,373,118,000	30,904,019

Fig. 1.

(*ii*) Inter-City Operation—250 to 1,000 miles

(*iii*) Medium Range Operation—1,000 to 2,000 miles

(*iv*) Long Range Operation—2,000 to 3,000 miles and upwards.

In addition, these categories practically define the aircraft types which are required for a world-wide air route pattern and will probably continue to do so for some time to come. In the first group we are, to a great extent, still dependent upon the veteran DC-3 which is being followed by newer types. This entirely excludes the helicopter or the small executive aeroplane operated by business companies or on a charter or private basis. The latter, particularly the amphibian and "ski-plane," have played a great part in the opening up of the Canadian North Country and other countries in the Commonwealth. There is no doubt that the opening up of the immensely rich mining areas of Northern Canada has been made possible by the aeroplane. The northern part of the Canadian Provinces must be visited to appreciate the task which the aeroplane has performed in overcoming the great distances over the forest and rock-covered country, often frozen and covered by snow and ice.

In the third and fourth groups, dominated by the DC-6, DC-4, DC-4M2, Constellation, and Strato-Cruiser, we have longer Empire routes, the Pacific and the important North Atlantic prestige route.

Nevertheless, from a traffic volume point of view, group (*ii*) covering the shorter range Inter-City stages is by far the most important. From Fig. 1 it can be seen that the ratio of domestic to international traffic in Canada for 1947 was approximately 4.5 to 1 and in 1948, 5.6 to 1: while the ratio of domestic to international and foreign traffic for the U.S.A. was 3.6 to 1 in 1947 and 3.8 to 1 in 1948. Apart from this it is the field where real and obvious advantages can be offered to the passengers without the inevitable strain and habit disturbances of long distance air travel.

No one can honestly pretend that at the present time trans-Atlantic air travel is other than third class. The only thing one can do is make the travelling time as short as possible so that the added effect of catching up with, or running away from the sun, can be mitigated as much as possible by completing the journey in a normal waking day, or preferably a sleeping night.

Some airlines are now offering bunk accommodation and this will be an alleviating factor, but speed is the only thing that counts. In any case, it is unlikely that airlines will be prepared, where the traffic is heavy enough, to forego the revenue which accrues from putting two seats where one bunk will go.

Inter-city travel, particularly if done quickly, has almost all the advantages and none of the disadvantages of surface travel.

We are rapidly approaching the time when the return journey of 1,000 miles each way between Toronto and Winnipeg can be made within say, 12 or 14 hours, waking time. This period will include three hours for the outward journey and three hours for the inward journey, and leaves ample time between the trips for three or four hours' business without having to sleep away from home.

In addition to this, it is the group in which aircraft and air traffic control development can most naturally take place first, without the hazards and weather problems of longer over-water flights.

Up to this time only two modern post-war inter-city transports have appeared on the scheduled routes, the Convair 240 and the Martin 202. Both are capable of taking a maximum payload of about 9,000 lb. including up to 40 passengers. A number of operators are using these aircraft but other operators, realising that in this stage range the effect of aircraft and engine development will be earliest felt, have refrained from committing themselves to the immediately available new types, fearing that they may become at a disadvantage when more advanced and faster types appear. For the time being, therefore, many operators are carrying on with DC-3s, DC-4s and even DC-6s on stage lengths for which these aircraft are entirely unsuited (to the detriment of operating economy) until the new aircraft arrive.

2. REGIONS FAVOURABLE TO DEVELOPMENT

The degree to which conditions exist favourable to the introduction of advanced types of aircraft, particularly the turbo-jet, vary greatly in different parts of the Commonwealth. Where operational problems are greater and the need for longer

Fig. 3.
Western European air routes suitable for jet aircraft operation.

stacking times more keenly felt the attitude is very different from that obtained in areas where conditions are easier, the weather good and there is no stacking problem. This, it seems, colours very much the outlook as to when the time will be ripe for the introduction of the jet, and as to whether the turbo-prop stage is worth while.

Although I have tried to be as unbiased as possible it is gratifying to note that it is not now so much a question of "whether" or "no" but rather "when," in talking of the turbo-jet. It is therefore of considerable interest to survey the various internal inter-city systems of the Commonwealth nations and the United States of America from this point of view, and to examine the conditions prevailing.

From such a survey some indication can be obtained of the justification for the intermediate turbo-prop stage. This requires careful consideration as it would inevitably saddle the operator once again with equipment with which, while more rapidly obsolescent, he would be loth to part in view of his financial investment.

In order to make this comparison, one should take into consideration complications arising out of the international frontiers and the consequent expectation of agreement in the novel operational techniques required. The readily achievable degree of standardisation of airborne and ground controls and landing aids, and also the possibility of the use of fog dispersal equipment and high intensity lighting, need to be reviewed in relation to the development period. This is quite apart from the present condition of the runways in the various regions.

3. AVAILABILITY OF MORE ADVANCED TYPES

Turbo-prop aircraft with a cruising speed of 300-350 m.p.h. and turbo-jet aircraft with a cruising speed of between 400 and 500 m.p.h. will be available shortly. Prototypes with adequate operational ranges up to 1,000 miles and payloads up to 11,000 or 12,000 lb. are already flying. It may be assumed therefore that they are technically feasible and that it only remains to demonstrate their economic soundness and competitive qualities in relation to existing reciprocating engine types.

4. REVIEW OF COMMONWEALTH ROUTES

Remembering the title of this paper it is perhaps appropriate, first to review the European, Empire, and U.S.A. internal routes from the point of view of their suitability for the introduction of the short range high speed passenger transport.

4.1. Typical European routes

Figure 2* shows the typical stages radiating from London. This indicates the place of the 250-800 miles' range transport, and at the same time brings out the international complications which are added to the notoriously fickle weather and consequent large stand-off allowances carried by European operators. While Western Europe is not troubled by extreme heat or extreme cold, there is a high incidence of bad flying weather and consequent stacking. In addition, a number of

* Figures 2, 4, 6, 8, 10 and 12 will be found between pp. 1024 and 1025.

airport runways at important cities, by modern standards, are insufficiently developed. In some cases night landings cannot be made. This reduces utilisation and detracts a great deal from the advantages of increased speed.

Apart from this it can be seen from Fig. 2 that most of the stages quoted are suitable for the operation of the turbo-jet transport. The exceptions are the London-Brussels, London - Paris, and London - Amsterdam stages which, while economical, are rather short and do not take full advantage of the considerable improvement in block to block time which is achieved on the longer stages of 400-600 miles. The map in Fig. 3 will also assist in visualising the conditions.

In all cases a worth while payload is carried which would not be unduly reduced by increase in stacking time, until such time as the traffic control will permit of the quoted allowances. In the meantime, the simpler systems and better weather conditions of other countries of the Commonwealth will be more favourable to the initial testing of the new transports.

4.2. Typical African routes

Typical South African stages are given in Fig. 4, which brings out the two important characteristics of South African operation, (*a*) the high altitude of the runways and (*b*) the high temperatures encountered.

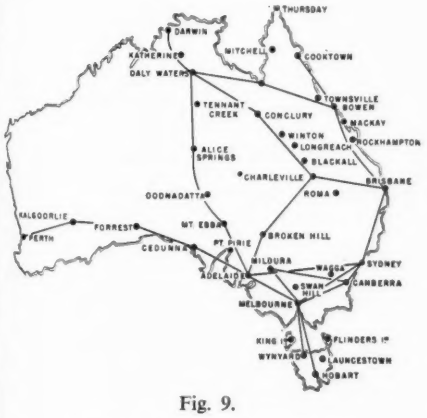


Fig. 9.

Australian air routes suitable for turbo-jet operation.

Fig. 5.

South African air routes suitable for jet aircraft operation.

The alternate distances are also rather high, nevertheless the payloads are generally well up towards maximum capacity in spite of the high altitudes and temperatures. From this it is apparent that the margin of power in the jet transport required for the higher speeds compensates for the inferior take-off thrust of the present jet engines. The take-off of the jet transport, therefore, is comparable with reciprocating engine and turbo-prop transport. Fig. 5 shows typical routes.

4.3. Typical Indian routes

Typical routes are shown in Figs. 6 and 7. Unfortunately I was unable to add the alternates and their runway lengths in the block distances. Nevertheless the main runways, altitudes, and temperatures ensure the carrying of full payload in most cases.

4.4. Typical Australian routes

Figures 8 and 9, showing the internal routes of Eastern Australia, bring out their eminent suitability for the adequate traffic control of the new development transports. Fig. 8 also shows the airport and weather suitability.

The runway lengths are good, although the average temperatures are rather high in some cases. In most cases full payload can be carried at less than the maximum permissible gross weight for take-off.

The generally good weather makes Australia by far the most suitable of the Commonwealth countries for the introduction of advanced high speed transports.

4.5. Typical Canadian routes

It is particularly appropriate to analyse the Canadian routes from this point of view. Canada has a simple but well-developed air transport system operated by two major airlines.

Nearly all the stage lengths are within the 200 to 500 mile bracket and none of the aerodromes are at any great altitude, with the exception of Calgary which is 3,555 ft.

On the whole Canada enjoys good and predictable weather over the majority of the routes and while the temperatures in the summer are high in the Middle West, being of the order of 100°F. and up to 90°F. for a few days elsewhere, this represents no great problem in temperature accountability. The runways which would be used for main inter-city operations are of adequate length and in a number of cases are being extended. The absence of international frontiers and the small number of operating airlines reduces the complications of joint airline operation from one airport to another. This is shown in Figs. 10 and 11.

Briefly, Canada is a very suitable place in which to introduce new types, particularly the jet aircraft in the initial stages of traffic control development.

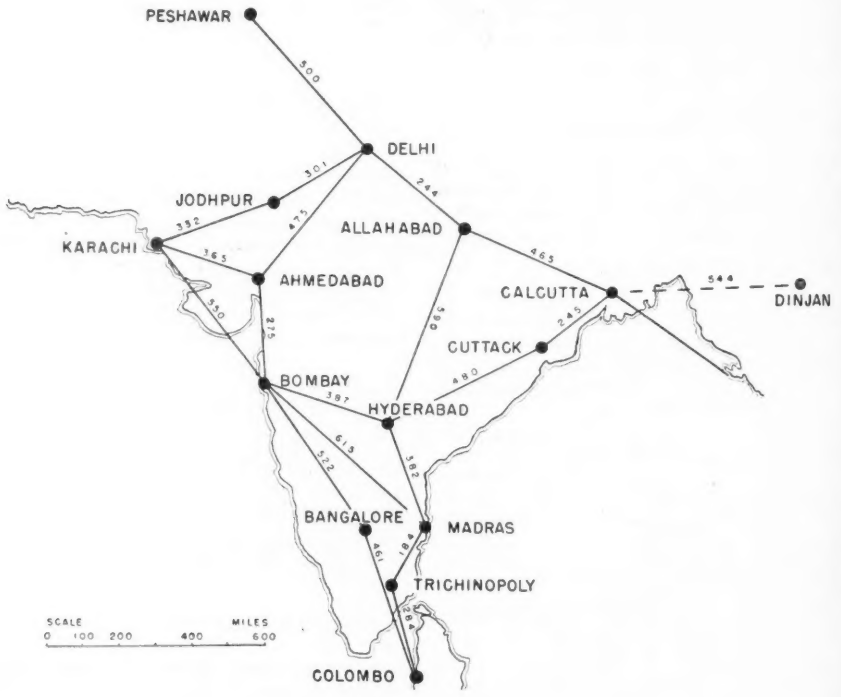


Fig. 7.

Indian air routes suitable for jet aircraft operation.

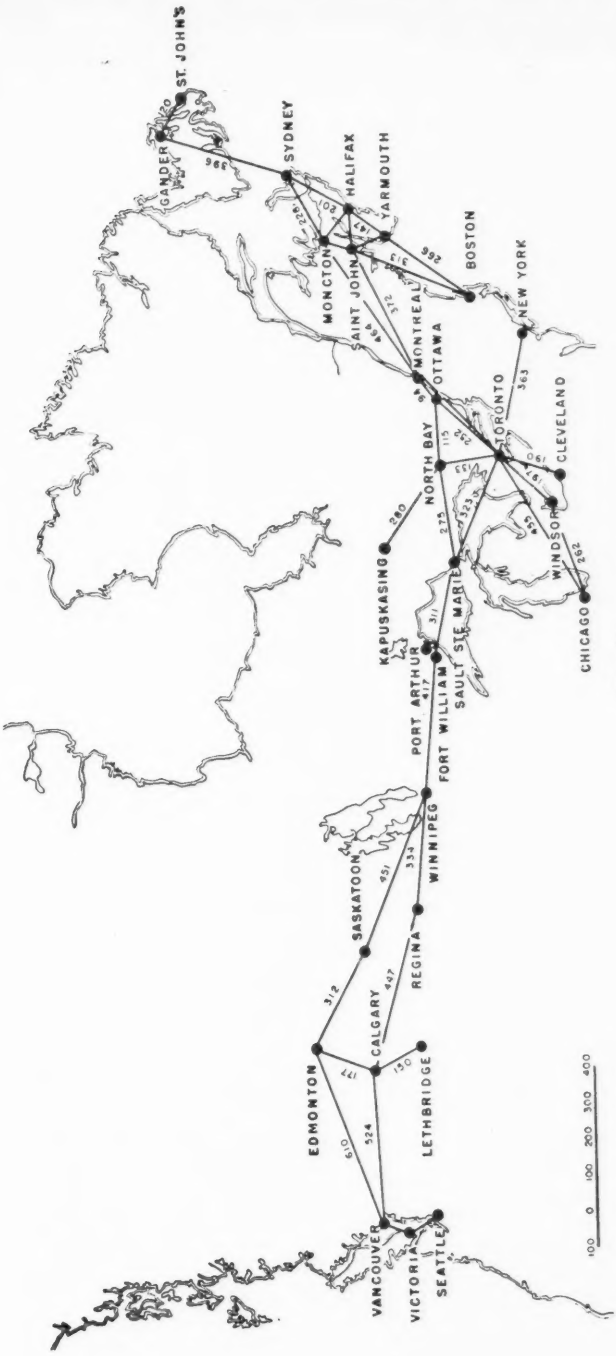


Fig. 11.
Canadian air routes suitable for jet aircraft operation.

5. SPEED

5.1. Effect of operating costs

The one factor which generally brings the biggest return to the operator is speed. This is because it gives more tonnage or passenger miles per 1,000 hours of annual utilisation, enables fewer aircraft to perform the same job, and so reduces the indirect operating costs of the airline. These costs are equal in importance to the more widely discussed direct costs.

As has been stated on other occasions, the true economy of an airline can only be arrived at by taking all aspects into account. This was clearly brought out by Masefield[2] in his paper in 1948.

A first step towards this can be made by combining direct and indirect costs. Indeed this is the only addition which need be made as these are the only costs borne by the airline; other costs such as aerodromes and associated ground equipment are borne by the appropriate government department. In this way a much more accurate picture can be obtained of operating economics and it will be shown later that, while the higher speed of the jet may have no lower direct costs, the indirect costs will be considerably less, resulting in a net reduction in total costs.

It should be quite clearly appreciated that speed enables the operator to make more money, quite regardless of whether or not anything is done to improve the time to transport the passenger to and from the city office. On a short journey the overall saving in time may be small, but it is the saving on the time in the aeroplane that counts so far as the operator is concerned.

By all means improve the ground handling time for the passengers, it is bad enough now in all conscience, but let us be quite clear about the question at issue.

5.2. The penalties of speed

Increased speed of operating, however, brings with it its own problems of refuelling, of traffic control and ground handling of aircraft and passengers and it is important

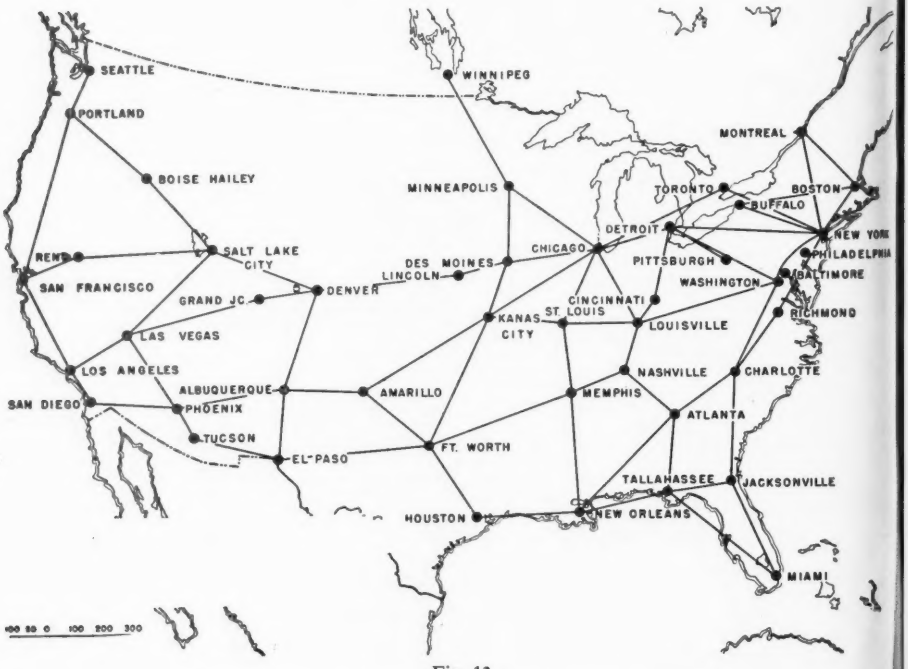


Fig. 13
United States air routes suitable for jet aircraft operation.

and it
higher
direct
lerably
l costs,
ed that
more
or not
me to
he city
saving
ing on
so far

ndling
gh now
e clear

owever,
uelling.
ing of
portant

OPERATIONAL ANALYSIS OF TYPICAL EUROPEAN AIR ROUT

Fuel reserve = 45 min. + flight to alternate destination.

From / To	1 *Block Distance* *(miles)*	2 *Gross Weight on Take-off* *(lb.)*	3 *Field Elevation* *(ft.)*	4 *Average Yearly Temperature* *(°F.)*	5 *Runway Length Available* *(ft.)*	6 *Distance Required for Take-off* *(ft.)*	7 *Distance Required for Landing at 52,500 lb.* *(ft.)*	8* *Required Field Length Determined by Landing Run/6* *(ft.)*	9 *Fuel Consumed to Destination* *(lb.)*	10 *Block Time to Destination* *(min.)*
London to	213	54960	80	63	8915	2650	——	4808	5900	55
Brussels			130	63	6800	——	2885	4817		
London to	215	56330	80	63	8915	2820	——	4808	5950	56
Paris			164	65	6890	——	2892	4825		
London to	229	55180	80	63	8915	2680	——	4808	6120	58
Amsterdam			13	62	7000	——	2880	4800		
London to	350	57200	80	63	8915	2870	——	4808	8000	77
Belfast			19	60	3360	——	2875	4792		
London to	375	59150	80	63	8915	3100	——	4808	8400	81
Glasgow			35	55	6536	——	2855	4763		
London to	455	59930	80	63	8915	3200	——	4808	9600	93
Bordeaux			154	62	6560	——	2880	4803		
London to	593	60000	80	63	8915	3200	——	4808	11680	114
Berlin			160	63	4500	——	2891	4820		
London to	606	60000	80	63	8915	3200	——	4808	11880	117
Copenhagen			10	62	5900	——	2880	4800		
London to	614	60000	80	63	8915	3200	——	4808	12000	117
Marseilles			26	72	6500	——	2912	4860		
London to	649	60000	80	63	8915	3200	——	4808	12500	123
Prague			1203	59	5900	——	2940	4917		

Fig. 2.

R ROUTES WITH A MODERN TURBO-JET TRANSPORT

* Field length required for unrestricted operation.

10	11	12	13	14	15	16	17	18	19
Block Time to Destination (min.)	*Block Speed to Destination* (m.p.h.)	*Alternate Airport* (name)	*Distance of Alternate from Destination* (miles)	*Alternate Field Elevation and Average Temperature* (ft.—°F.)	*Runway Length Required for Landing* (ft.)	*Runway Length Available* (ft.)	*Fuel Consumed to Alternate* (lb.)	*Fuel Required for Flight* (lb.)	*Payload* (lb.)
55	232	Lille	65	147′ 65°	4130	3560	5250	11150	12500
56	232	Brussels	158	130′ 63°	4130	4880	6800	12750	12500
58	238	Eindhoven	65	66′ 60°	4110	3560	5220	11340	12500
77	273	Dublin	75	220′ 60°	4120	3700	5233	13233	12500
81	278	Manchester	185	235′ 61°	4130	5250	6000	14400	12500
93	293	Toulouse	155	482′ 65°	4170	4830	5740	15340	12500
114	311	Hamburg	160	40′ 62°	4043	4900	4800	16480	10860
117	312	Aalborg	148	3′ 62°	4114	4750	5900	17780	10810
117	314	Nice	95	10′ 65°	4120	4000	4430	16430	11440
123	317	Brno	122	900′ 60°	4180	4360	Unknown	16860	10580

OPERATIONAL ANALYSIS OF TYPICAL SOUTH AFRIC

Fuel reserve = 45 min. + flight to alternate destination.

From / To	1 *Block Distance* (miles)	2 *Gross Weight on Take-off* (lb.)	3 *Field Elevation* (ft.)	4 *Average Yearly Temperature* (°F.)	5 *Runway Length Available* (ft.)	6 *Distance Required for Take-off* (ft.)	7 *Distance Required for Landing at 52,500 lb.* (ft.)	8* *Required Field Length Determined by Landing Run/6* (ft.)	9 *Fu Consu to Destin* (lb
Capetown to Beaufort W.	262	58420	50 2850	85°	4650 6300	3425 ——	—— 3165	4933 5275	66
Capetown to Kimberley	540	60000	50 3926	85°	4650 7200	3625 ——	—— 3245	4933 5408	109
Port Elizabeth to Durban	440	60000	800 S. L.	85°	6000 4000	3965 ——	—— 2955	5025 4925	94
Johannesburg to Kimberley	290	56400	5160 3926	85°	6000 10500	4650 ——	—— 3245	5600 5408	70
Johannesburg to Salisbury	675	60000	5160 4780	85°	6000 6900	5500 ——	—— 3320	5600 5533	128
Capetown to Bloemfontein	590	60000	50 4660	85°	4650 7400	3625 ——	—— 3320	4933 5533	116

AFRICAN AIR ROUTES WITH A MODERN TURBO-JET TRANSPORT

* Field length required for unrestricted operation.

	9	10	11	12	13	14	15	16	17	18	19
eld d ng	*Fuel Consumed to Destination* (lb.)	*Block Time to Destination* (min.)	*Block Speed to Destination* (m.p.h.)	*Alternate Airport* (name)	*Distance of Alternate from Destination* (miles)	*Alternate Field Elevation and Average Temperature* (ft.—° F.)	*Runway Length Required for Landing* (ft.)	*Runway Length Available* (ft.)	*Fuel Consumed to Alternate* (lb.)	*Fuel Required for Flight* (lb.)	*Payload* (lb.)
	6600	64	249	Capetown	262	50′ 85°	4650	4260	6320	12920	12500
	10900	107	305	Victoria W.	210	3926′ 85°	4636	5100	5610	16510	10930
	9400	91	290	Lourenco Marques	300	200′ 85°	4250	4500	6880	16280	11160
	7050	68	258	Bloem-fontein	86	4660′ 85°	4530	7400	3850	10900	12500
	12850	127	319	Lourenco Marques	300	200′ 85°	4250	4500	6880	19730	7710
	11600	114	311	Kimberley	86	3926′ 85°	4636	10500	3850	15450	11990

Fig. 4.

OPERATIONAL ANALYSIS OF TYPICAL INDIAN

Fuel reserve = 45 min. + flight to alternate destination.

From / To	1 Block Distance (miles)	2 Gross Weight on Take-off (lb.)	3 Field Elevation (ft.)	4 Average Yearly Temperature (°F.)	5 Runway Length Available (ft.)	6 Distance Required for Take-off (ft.)	7 Distance Required for Landing at 52,500 lb. (ft.)	8* Required Field Length Determined by Landing Run/6 (ft.)	
Karachi to Bombay	550	60000	75	80	7500	3525	——	4910	11
			10	82	6000	——	2940	4900	
Bombay to Bangalore	522	60000	10	82	6000	3550	——	4900	10
			400	84	Unknown	——	2985	4975	
Trichinopoly to Colombo	284	57200	290	84	7200	3300	——	4960	7
			15	82	4800	——	2946	4910	
Delhi to Peshawar	500	60000	720	75	6000	3600	——	4960	10
			980	70	5000	——	2970	4950	
Calcutta to Allahabad	465	59950	14	84	6000	3600	——	4925	9
			600	78	5000	——	2955	4925	
Delhi to Karachi	630	60000	720	75	6000	3600	——	4960	12
			75	80	7500	——	2946	4910	
Bombay to Hyderabad	387	58800	10	82	6000	3400	——	4900	8
			380	82	5000	——	2965	4940	
Hyderabad to Madras	382	58700	380	84	5000	3525	——	4975	8
			49	84	6000	——	2960	4933	

NDIAN AIR ROUTES WITH A MODERN TURBO-JET TRANSPORT

* Field length required for unrestricted operation.

	9	10	11	12	13	14	15	16	17	18	19
red ength ained ading /6)	*Fuel Consumed to Destination* (lb.)	*Block Time to Destination* (min.)	*Block Speed to Destination* (m.p.h.)	*Alternate Airport* (name)	*Distance of Alternate from Destination* (miles)	*Alternate Field Elevation and Average Temperature* (ft.—° F.)	*Runway Length Required for Landing* (ft.)	*Runway Length Available* (ft.)	*Fuel Consumed to Alternate* (lb.)	*Fuel Required for Flight* (lb.)	*Payload* (lb.)
0 0	11000	108	306	Unknown	120	200′ 80°	4220	Unknown	4700	15700	11740
0 5	10600	104	303	Unknown	120	200′ 80°	4220	Unknown	4700	15300	12140
0 0	7000	67	256	Unknown	120	200′ 80°	4220	Unknown	4700	11700	12500
0 0	10300	100	300	Unknown	120	200′ 80°	4220	Unknown	4700	15000	12440
5 5	9750	95	295	Unknown	120	200′ 80°	4220	Unknown	4700	14450	12500
0 0	12200	120	315	Unknown	120	200′ 80°	4220	Unknown	4700	16900	10540
0 0	8600	83	281	Unknown	120	200′ 80°	4220	Unknown	4700	13300	12500
5 3	8500	82	280	Unknown	120	200′ 80°	4220	Unknown	4700	13200	12500

Fig. 6.

OPERATIONAL ANALYSIS OF TYPICAL AUSTRALIAN A

Fuel reserve = 45 min. + flight to alternate destination.

From / To	1 *Block Distance* (miles)	2 *Gross Weight on Take-off* (lb.)	3 *Field Elevation* (ft.)	4 *Average Yearly Temperature* (°F.)	5 *Runway Length Available* (ft.)	6 *Distance Required for Take-off* (ft.)	7 *Distance Required for Landing at 52,500 lb.* (ft.)	8* *Required Field Length Determined by Landing Run/6* (ft.)	9 *Fuel Consumed to Destination* (lb.)
Melbourne to Adelaide	410	58700	265	70	5800	3225	——	4875	8950
			60	75	7500	——	2925	4875	
Melbourne to Sydney	440	59630	265	70	5800	3325	——	4875	9400
			10	75	5900	——	2920	4867	
Melbourne to Hobart	381	57850	265	70	5800	3100	——	4875	8450
			30	60	4500	——	2875	4792	
Sydney to Brisbane	472	59730	10	75	5900	3375	——	4850	9850
			55	80	6000	——	2940	4900	
Darwin to Daly Waters	315	57650	90	100	10000	3625	——	5017	7450
			700	90	5500	——	3020	5033	
Daly Waters to Alice Springs	523	60000	700	90	5500	3940	——	5033	10600
			1793	85	5250	——	3095	5158	
Alice Springs to Mount Ebba	459	60000	1793	85	5250	4150	——	5158	9700
			700	80	5420	——	2985	4992	
Mount Ebba to Adelaide	345	57700	700	80	5420	3380	——	4992	7950
			60	75	7500	——	2930	4883	
Sydney to Adelaide	730	60000	60	75	7500	3425	——	4850	13600
			10	75	5900	——	2925	4875	

Fig

LIAN AIR ROUTES WITH A MODERN TURBO-JET TRANSPORT

* Field length required for unrestricted operation.

9	10	11	12	13	14	15	16	17	18	19
Fuel Consumed to Destination (lb.)	*Block Time to Destination* (min.)	*Block Speed to Destination* (m.p.h.)	*Alternate Airport* (name)	*Distance of Alternate from Destination* (miles)	*Alternate Field Elevation and Average Temperature* (ft.—°F.)	*Runway Length Required for Landing* (ft.)	*Runway Length Available* (ft.)	*Fuel Consumed to Alternate* (lb.)	*Fuel Required for Flight* (lb.)	*Payload* (lb.)
8950	86	285	Port Pirie	113	40′ 75°	4183	4250	4500	13450	12500
9400	91	290	Canberra	148	1850′ 75°	4357	4730	6800	16200	12500
8450	82	280	Western Junction	90	560′ 65°	4157	3900	4000	12450	12500
9850	96	296	Evans Head	118	15′ 80°	4200	4380	4320	14170	12500
7450	71	265	Katherine	146	360′ 90°	4271	4700	5000	12450	12500
10600	104	303	Codnadata	277	370′ 85°	4300	6550	5000	15600	10290
9700	94	294	Ceduna	168	70′ 75°	4180	5030	5800	15500	12500
7950	76	272	Port Pirie	113	40′ 75°	4183	4250	4500	12450	12500
13600	135	324	Port Pirie	113	40′ 75°	4183	4250	4500	18100	9590

Fig. 8.

OPERATIONAL ANALYSIS OF TYPICAL CANADIAN AIR RO

Fuel reserve = 45 min. + flight to alternate destination.

From / To	1 *Block Distance* (miles)	2 *Gross Weight on Take-off* (lb.)	3 *Field Elevation* (ft.)	4 *Average Yearly Temperature* (°F.)	5 *Runway Length Available* (ft.)	6 *Distance Required for Take-off* (ft.)	7 *Distance Required for Landing at 52,500 lb.* (ft.)	8* *Required Field Length Determined by Landing Run/6* (ft.)	9 *Fuel Consumed to Destination* (lb.)	10 *Blo Tin to Destin* (mi
Toronto to Montreal	337	57250	555 105	58 54	5000 7000	2900 —	— 2860	4833 4767	7800	7
Toronto to New York	363	57900	555 20	58 60	5000 6000	2990 —	— 2880	4833 4800	8200	7
Toronto to Chicago	455	58900	555 615	58 68	5000 6545	3075 —	— 2940	4833 4900	9600	9
Toronto to Ottawa	252	55950	555 355	58 54	5000 4100	2750 —	— 2880	4833 4800	6500	6
Winnipeg to Ft. William	417	58450	775 655	53 54	6200 4700	2950 —	— 2900	4833 4833	9050	8
Saskatoon to Winnipeg	451	59675	1625 775	53 53	5500 6200	3300 —	— 2900	4925 4833	9550	9
Edmonton to Saskatoon	312	57825	2200 1625	53 53	5870 5500	3225 —	— 2958	5000 4930	7400	7
Calgary to Vancouver	524	60000	3555 5	53 59	6200 5200	3875 —	— 2870	5167 4783	10650	10
Halifax to Sydney	201	57075	170 200	55 55	5890 5000	2740 —	— 2870	4775 4783	5700	5
Sydney to Gander	396	59620	200 495	55 45	5000 6000	3050 —	— 2850	4783 4750	8720	8
Montreal to Moncton	464	60000	105 230	54 58	7000 7000	3025 —	— 2885	4767 4808	9750	9

Fig. 10.

AIR ROUTES WITH A MODERN TURBO-JET TRANSPORT

* Field length required for unrestricted operation.

	10	11	12	13	14	15	16	17	18	19
d on	*Block Time to Destination* (min.)	*Block Speed to Destination* (m.p.h.)	*Alternate Airport* (name)	*Distance of Alternate from Destination* (miles)	*Alternate Field Elevation and Average Temperature* (ft.—° F.)	*Runway Length Required for Landing* (ft.)	*Runway Length Available* (ft.)	*Fuel Consumed to Alternate* (lb.)	*Fuel Required for Flight* (lb.)	*Payload* (lb.)
	75	270	Ottawa	93	355′ 55°	4114	4100	3950	11750	12500
	79	276	Phila-delphia	111	10′ 65°	4130	5400	4200	12400	12500
	94	293	Milwaukee	82	676′ 65°	4200	6700	3800	13400	12500
	62	246	Montreal	93	105′ 54°	4093	7000	3950	10450	12500
	88	286	Houghton	88	178′ 54°	4100	4000	3900	12950	12500
	93	292	Rivers	140	800′ 53°	4143	4000	4625	14175	12500
	71	264	Regina	162	1890′ 53°	4250	3770	4925	12325	12500
	104	303	Seattle	129	25′ 60°	4110	7520	4475	15125	12315
	54	227	Moncton	228	230′ 55°	4100	7000	5875	11575	12500
	85	282	Stephen-ville	194	500′ 45°	4086	4000	5400	14120	12500
	95	295	Pennfield	151	260′ 58°	4070	5100	4800	14550	12500

Fig. 10.

OPERATIONAL ANALYSIS OF TYPICAL AMERICAN AI

Fuel reserve = 45 min. + flight to alternate destination.

From / To	1 *Block Distance* (miles)	2 *Gross Weight on Take-off* (lb.)	3 *Field Elevation* (ft.)	4 *Average Yearly Temperature* (°F.)	5 *Runway Length Available* (ft.)	6 *Distance Required for Take-off* (ft.)	7 *Distance Required for Landing at 52,500 lb.* (ft.)	8* *Required Field Length Determined by Landing Run/6* (ft.)	9 *Fuel Consumed to Destination* (lb.)
New York to Washington	217	55770	19 17	60 68	6000 6900	2650 ——	—— 2900	4800 4833	5920
New York to Buffalo	295	57750	19 711	60 60	6000 5600	2850 ——	—— 2915	4800 4860	7150
Buffalo to Chicago	465	58880	711 618	60 68	5600 6500	3175 ——	—— 2940	4860 4900	9750
Chicago to Minneapolis	365	58510	618 834	68 60	6500 5900	3225 ——	—— 2925	4900 4875	8250
Houston to Dallas	237	57720	50 483	75 74	4700 5500	3175 ——	—— 2940	4875 4900	6220
L. Angeles to San Francisco	335	57150	101 10	70 63	6000 8000	3025 ——	—— 2880	4860 4800	7800
Jacksonville to Miami	334	59000	52 10	75 75	7100 7400	3300 ——	—— 2920	4875 4867	7800
Washington to Louisville	478	59700	17 480	70 65	6900 5000	3300 ——	—— 2920	4840 4867	10000
Chicago to Kansas City	425	58550	618 746	68 70	6500 6500	3225 ——	—— 2955	4900 4925	9200
Jacksonville to Richmond	565	60000	52 167	75 73	7100 5200	3425 ——	—— 2925	4875 4875	11300
New Orleans to Houston	310	58880	10 50	75 75	7000 4700	3250 ——	—— 2925	4875 4875	7400

Fig.

CAN AIR ROUTES WITH A MODERN TURBO-JET TRANSPORT

* Field length required for unrestricted operation.

9	10	11	12	13	14	15	16	17	18	19
Fuel Consumed to Destination (lb.)	*Block Time to Destination* (min.)	*Block Speed to Destination* (m.p.h.)	*Alternate Airport* (name)	*Distance of Alternate from Destination* (miles)	*Alternate Field Elevation and Average Temperature* (ft.—° F.)	*Runway Length Required for Landing* (ft.)	*Runway Length Available* (ft.)	*Fuel Consumed to Alternate* (lb.)	*Fuel Required for Flight* (lb.)	*Payload* (lb.)
5920	56	233	Philadelphia	120	10′ 65°	5400	4130	4350	10270	12500
7150	68	260	Cleveland	175	789′ 65°	6000	4200	5100	12250	12500
9750	95	295	South Bend	70	776′ 65°	4800	4200	3630	13380	12500
8250	80	276	Duluth	150	1428′ 58°	5700	4236	4760	13010	12500
6220	59	241	Houston	237	50′ 75°	4700	4180	6000	12220	12500
7800	75	270	Sacramento	85	21′ 70°	6000	4157	3850	11650	12500
7800	75	270	Tampa	215	26′ 75°	7000	4186	5700	13500	12500
10000	97	297	Cincinnati	110	488′ 65°	4100	4165	4200	14200	12500
9200	89	288	Topeka	65	879′ 70°	4300	4236	3850	13050	12500
11300	110	308	Washington	120	17′ 68°	6900	4143	4350	15650	11790
7400	71	262	Dallas	235	483′ 74°	5500	4214	5980	13380	12500

Fig. 12.

tha
on
sol

6.

fo
(a)

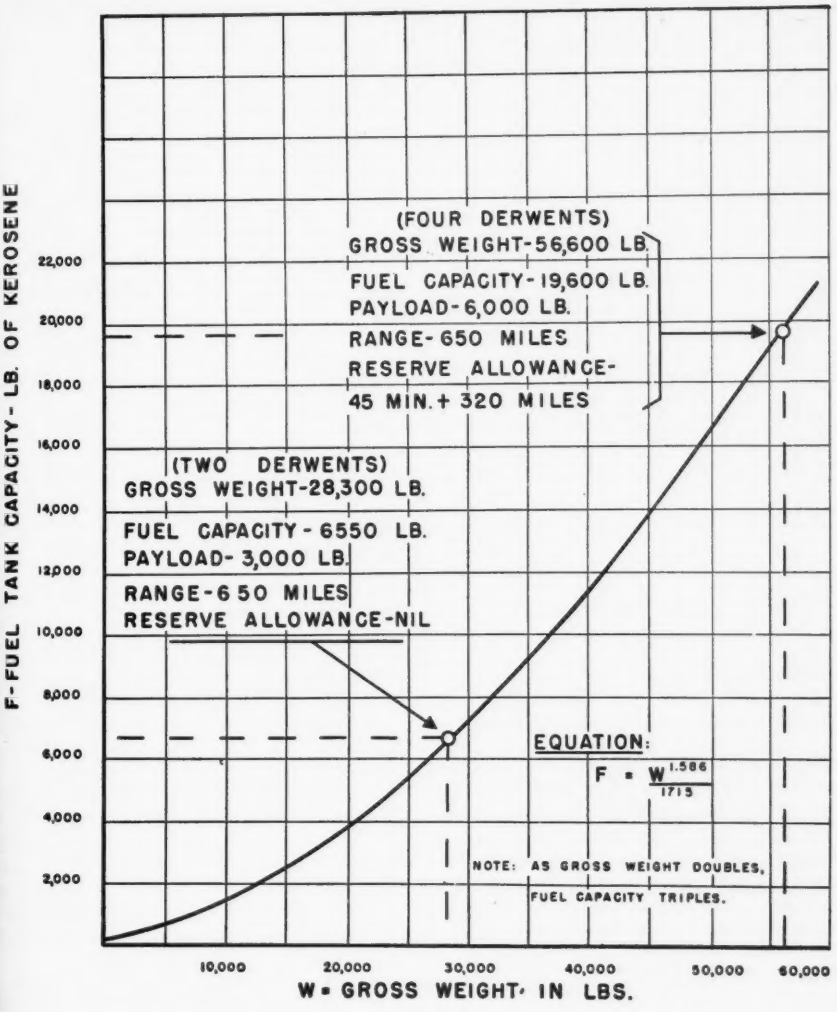


Fig. 14.
Relationship between gross weight and fuel capacity of pure jet aircraft

that the designers and operators co-operate on these questions and work out the best solutions together.

6. TYPES OF AIRCRAFT

Types of aircraft which may be considered for the future inter-city routes are:—

(*a*) Reciprocating-engined transports.

(*b*) Turbo-prop transports.

(*c*) Turbo-jet transports.

(*d*) Compounded reciprocating engined transports.

While (*a*) is current, (*d*) may be discounted for short range operations, hence discussion should centre around (*b*) and (*c*) by comparing both with (*a*).

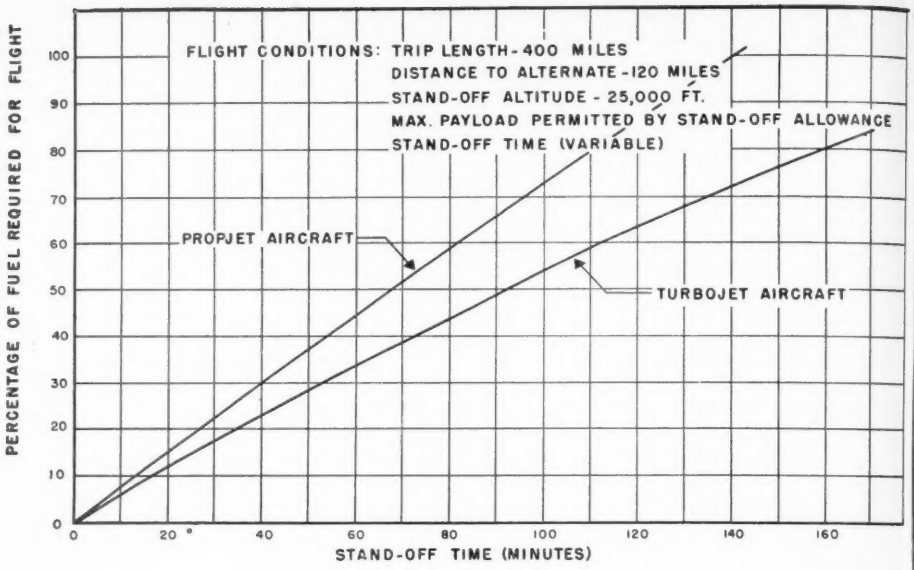


Fig. 15.
Variation of fuel (for a given flight) with stand-off allowance.

7. AIRCRAFT SIZE

Aircraft size is an important parameter.

In the past entirely misleading comparisons have been made by taking the wrong size of aircraft. If, say, a twin-Derwent transport of 28,000 lb. gross weight is studied, the conclusion will undoubtedly be reached that only the most meagre (or alternatively, most optimistic) emergency allowances will show the aircraft to be able to fly 500 or 600 miles. If, however, one studies an aircraft of twice the size (and power) it will be found to be able to fly 500 or 600 miles with reasonable allowances.

This is shown strikingly in Fig. 14 which shows the amount of fuel it is physically possible to put into an aircraft of given size. It is easy to see by the law of similarity that the available tank capacity is proportional to (*Take-off Weight*)$^{\frac{3}{2}}$. This of course applies only to geometrically similar fuel tank arrangements. If radical departures are made by putting large amounts of fuel in the fuselage, the advantage of size is even greater.

In fact, it is slightly better than this as the bigger the aircraft the more feasible does the use of odd spaces in the structure become. For twice the size, nearly three times the amount of fuel can be carried to supply twice the number of engines, hence, there is roughly another 50 per cent. additional fuel emergency allowance.

There is nothing novel in this conclusion as it is well known that range is a function of size. An aircraft to fly London-New York non-stop, with the usual allowances, has to be of the order of 120,000 lb. all-up weight. An aircraft of half the weight will only fly, say, two-thirds the distance or, alternatively, all the way with no allowances.

It is now proposed to compare the turbo-prop and turbo-jet transport aircraft of the near future and to relate them to the current reciprocating engine types.

Such a discussion turns almost entirely on engine development, and in what follows an endeavour will be made to base the discussion on reasonable expectations in engine development and to indicate the effect on operating economy of assumed degrees of improvement.

For the purpose of comparison, it is reasonable to take aircraft in the short range field of 40,000-60,000 lb. all-up weight range, or in other words, the 40-60 passenger aircraft. This is equivalent to 8,000 to 12,000 lb. payload.

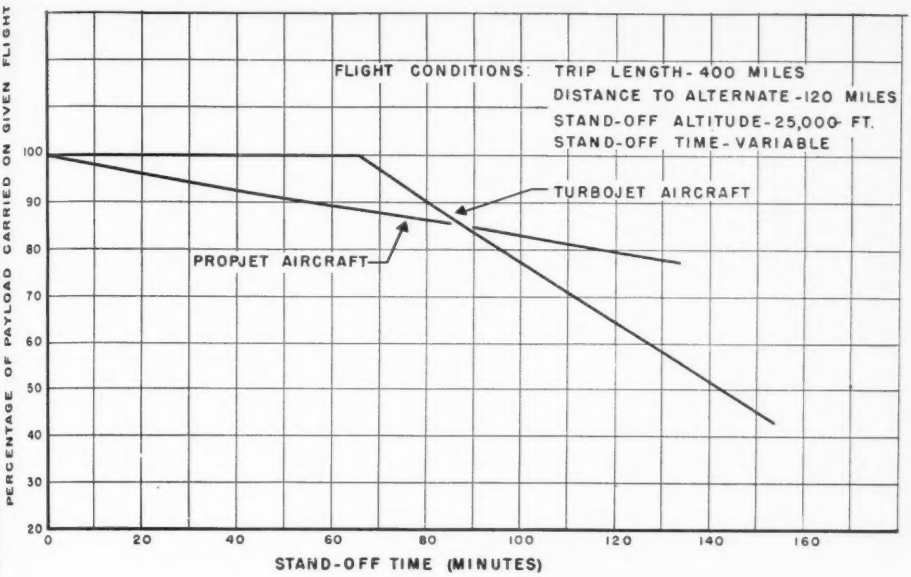


Fig. 16.
Variation of payload (for a given flight) with stand-off allowance.

It is felt that short range aircraft in this bracket will fill the needs of the operators for some years to come. The increasing traffic densities in Canada and the U.S.A., as well as in other parts of the Commonwealth, indicate that the 40-60 passenger aircraft will give the best compromise between aircraft size and traffic frequency.

At the same time it is a satisfactory starting point for the new aircraft, from a technical and economic viewpoint, giving reasonable immediate advantages in operating efficiency.

8. FUEL ALLOWANCES

Keeping in mind what I have said about the effect of aircraft size on fuel allowances, I would like to review the much discussed question of allowances and the ability of the three types to carry them.

The three debatable allowances are:—

(*i*) Taxi-ing allowance

(*ii*) The stand-off or stacking allowance

(*iii*) (*a*) The alternate allowance

(*b*) The descent allowance before going to alternate.

With the exception of (*i*), these are in the emergency category and are distinct from the fuel required for a normal operation based upon requirements which are common to all types of aircraft.

8.1. Taxi-ing allowance

It will not be possible to tolerate protracted taxi-ing and run-up times prior to actual take-off. Hence a new conception of aircraft handling will be required.

Fortunately, the jet engine does not require any appreciable warm-up time so that the dispersal of the aircraft adjacent to the take-off point is the most practical answer. The engines then need only be run immediately before take-off.

This was proposed by a senior member of a well-known airline who considers that specially designed passenger transport vehicles can take the passengers from the airport building to the aircraft. In this way the passengers will be completely protected from the weather. This is certainly not the case now; at present it is a common experience on many airports to struggle to or from the aircraft through rain, snow or ice at temperatures ranging from tropical to 30° below. On the other hand, the manner in which passengers can be handled at main

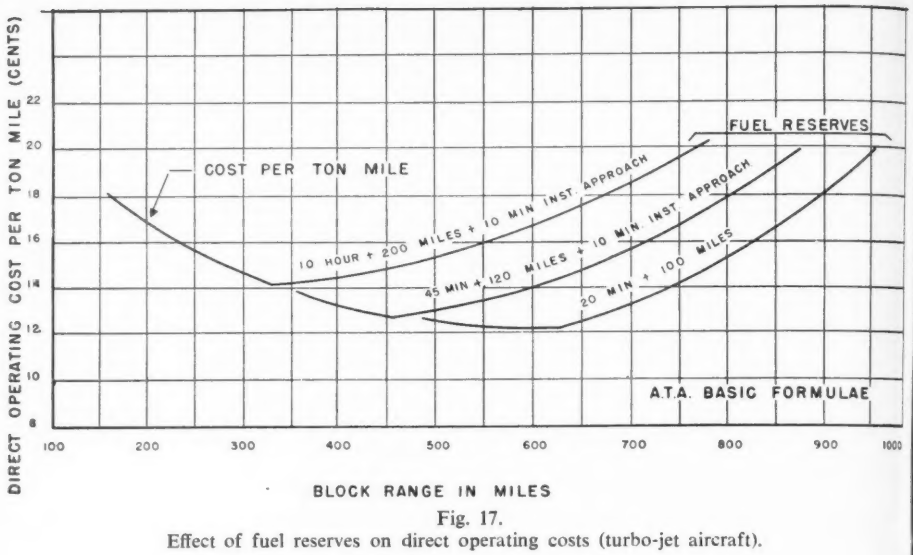


Fig. 17.
Effect of fuel reserves on direct operating costs (turbo-jet aircraft).

airports, such as Heath Row, now shows that the proposal is feasible.

In this way the impact of the jet transport will force the operator to move the passenger about on the ground in much greater comfort. This is quite apart from the desire of the operator to alleviate the lot of the passenger in order to enhance the attraction of air travel.

The wastage of fuel prior to take-off will be eliminated, the normal pre-flight fuel can be carried as an overload and the passengers will be much more comfortable than they are now.

8.2. Stand-off or stacking allowances

This allowance, which is pretty well directly proportional to shortcomings in operating "know how," is well known to be the biggest handicap for the jet and the least for the reciprocating engine, the turbo-prop being in between.

Much of the argument for and against the future transport turns on this and many light-hearted statements have been made on the subject without too much thought or investigation. Some details, therefore, may not be out of place. Fig. 15 gives the fuel required for stand-off as a percentage of the normal fuel, Fig. 16 gives the effect on payload and Figs. 17 and 18 give the effect on direct operating costs.

This shows that the jet aircraft, while taking a penalty does not suffer unduly. It will be seen later that it gains much more relatively, than the reciprocating engine and the turbo-prop through improvements in engine economy.

8.3. Alternate allowances

This allowance must obviously be carried by all aircraft for some time to come, but there is a part of the alternate allowance which is worthy of separate consideration. This may be described by (*iii*) (*b*) and implies important changes in operational control technique. This is because the omission of the pass at the primary destination airport means direction of the pilot by the ground organisation personnel who must decide for themselves as regards landing conditions. Pending improvement in visibility assessment methods, such a change undoubtedly means conservatism on the part of the ground control and consequently more diversions after departure. Nevertheless, the reduction in block to block time for the inter-city aircraft will ensure more accurate weather prediction for a shorter time ahead and thus, fewer actual diversions.

When diversion is necessary it is unreasonable to bring a turbo-prop or turbo-jet all the way down from 20,000 or 30,000 ft. in case of doubt in order to look at the airport. If

the weather is bad it is then necessary to consume large quantities of fuel climbing again to height before going to the alternate.

The various points in the operating procedure for the various types can be brought out very clearly pictorially and this has been done in Figs. 19 and 20. The times, distances, and fuel consumptions for the various parts of the operation can be picked out.

In particular, there is the importance of avoiding the descent at the destination before going to the alternate, mentioned previously. The distance to cruising height and the distance for the descent also indicates the minimum practical operating distance and so on. Another point is that it is unnecessary to climb or descend through the lower 10,000 to 15,000 ft. faster than 200 I.A.S. and in this way the incidence of severe bumps can be avoided. At greater altitudes the importance of gust alleviation has yet to be established.

If gust alleviation becomes a necessity then a mechanical aerodynamic device, rather than the adoption of swept-back wings, appears to be indicated as the weight penalty of the swept-back wing is great.

9. FLEXIBILITY OF OPERATION

There is also the question of the flexibility of operation of the jet engine which is so often quoted as one of the biggest difficulties of jet transport operation. The view is prevalent that the jet aircraft (and to a slightly lesser extent the turbo-prop aircraft) suffers from severe inflexibility of cruising and altitude operating conditions; this is very much exaggerated, as an investigation of four, three and twin-engine operation at various altitudes indicates.

Hetzel of Northrop Aircraft Inc.[3] has also drawn attention to this and shown that by using the right number of engines for the altitude, the jet can stack at any altitude without any appreciable penalty on fuel economy. This is shown in Fig. 21 and is quite apart from any improvements in the slow running economy, and so on, arising out of intake area control, or variable nozzle control, which are bound to emerge from the work which is being done in this field now.

Therefore, provided that an aircraft which is stacked for any length of time is definitely being brought in to the scheduled destination, there is complete flexibility of altitude and no penalty in economy.

As far as restarting in the air is concerned this can be accepted as a reasonable procedure.

This and the previous discussion on stacking are a strong argument for the four-engined aircraft which not only gives greater safety but also much greater flexibility of operation.

10. OPERATING ECONOMY

The crucial test of an aircraft is its ability to earn money for the operator. In this

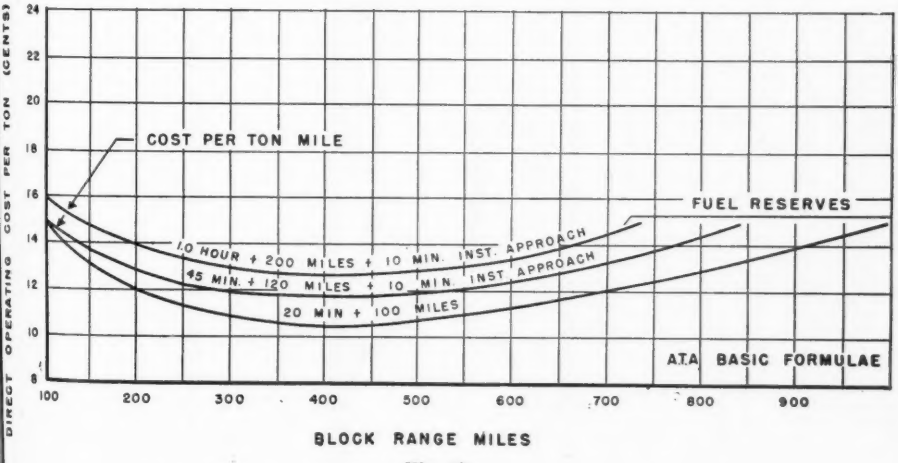


Fig. 18.
Effect of fuel reserves on direct operating costs (prop-jet aircraft).

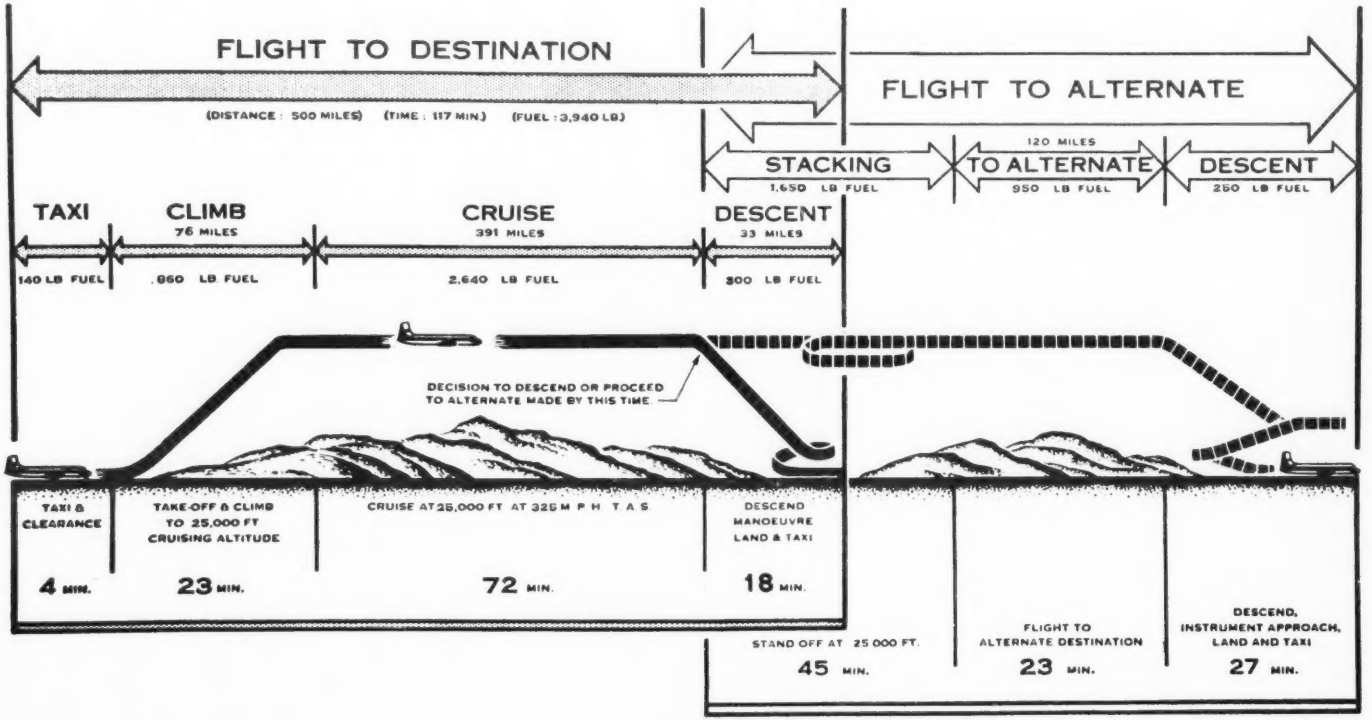


Fig. 19.
Prop-jet flight plan.

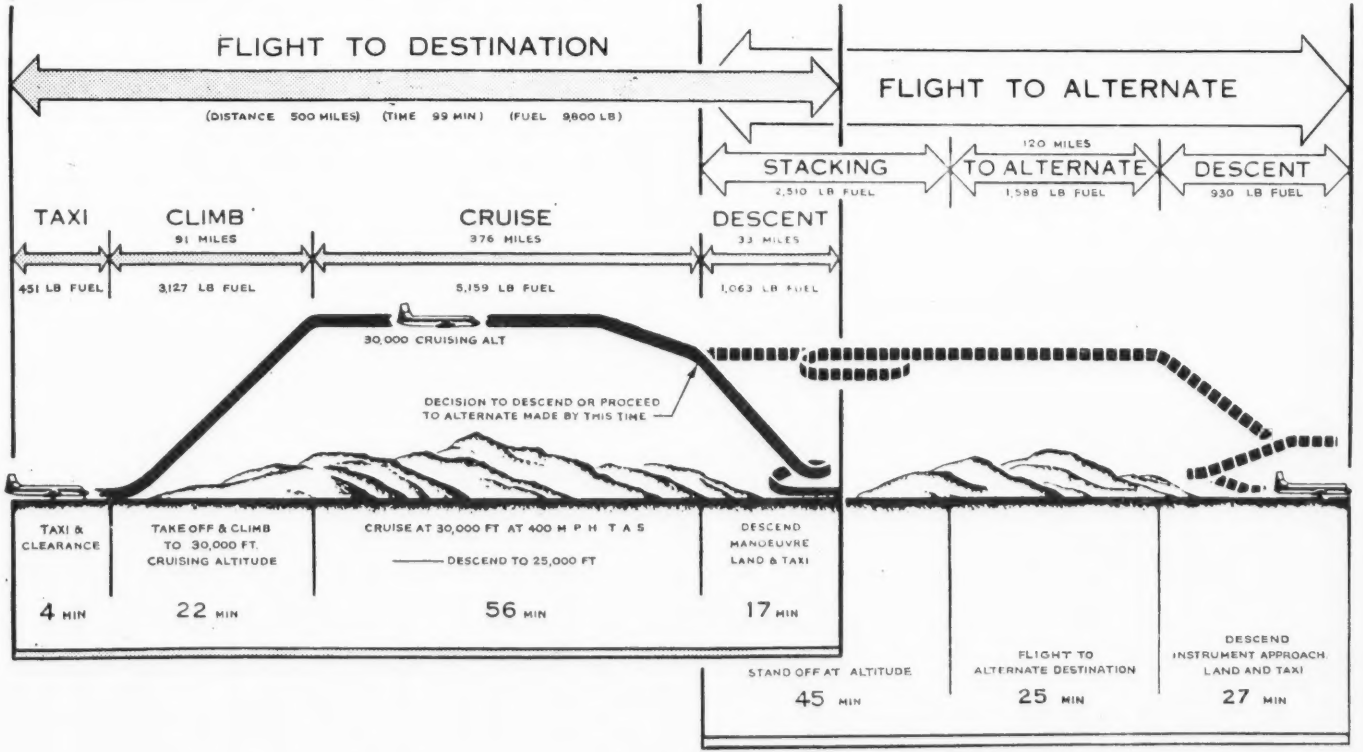


Fig. 20.
Jet flight plan.

RESERVE REQUIREMENTS FOR A TYPICAL JET TRANSPORT AT VARIOUS ALTITUDES

	Altitude	200 mi. at mi./lb.	lb. for 200 mi.	45 min. at hrs./10,000 lb.	lb. for 45 min.	Total Reserve lb.
4 Engines	0	.028	7140	1.405	5340	12480
	5,000	.03275	6110	1.535	4880	10990
	10,000	.03675	5440	1.63	4600	10040
	20,000	.04625	4330	1.765	4250	8580
	30,000	.0555	3610	1.835	4090	7700
Optimum No. Engines	0	(2) .034	5890	(2) 1.775	4220	10110
	5,000	(2) .0375	5340	(2) 1.870	4010	9350
	10,000	(3) .0397	5030	(2) 1.83	4100	9130
	20,000	(3) .047	4260	(3) 1.84	4070	8330
	30,000	(4) .0555	3610	(4) 1.835	4090	7700

Fig. 21.

DIRECT OPERATING COSTS OF A 4-ENGINED JET TRANSPORT COMPARED WITH AIRCRAFT POWERED BY RECIPROCATING AND PROP-JET ENGINES

(B) Air Transport Association Method of Computation

Expense Account	Cost Per Revenue Hour Rates Dollars		
	Jet Engine	*Reciprocating Engine*	*Prop-jet Engine*
I. Constant Cost/Revenue Hour:			
Oil Cost	0.23*	2.90	.23*
Engine Overhaul and Repair Cost	16.15*	9.97	16.50*
A/C Overhaul and Repair Cost	15.74	15.74	15.74
A/C & Engine Ground Service Cost	6.91*	13.78	11.80*
A/C Depreciation Cost	20.32	20.32	20.32
Engine Depreciation Cost	10.00	6.66	12.30
Total: Constant Cost/Revenue Hr.	69.35	69.37	76.89
II. Fuel Cost/Revenue Hour:	$C_f W_f$*	$C_f W_f$	$C_f W_f$*
	$6.7T_b$	$6T_b$	$6.7T_b$
III. Costs Varying with Block Speed:			
Cost/Revenue Hour			
First Pilot's Cost		$6.699 + 0.0195\ V_b$	
Co-Pilot's, Engineer's or Radio Operator's Cost		$2.329 + 0.0146\ V_b$	
Cabin Attendant's Cost		$0.9511 + 0.00594\ V_b$	
Crew Expenses		$0.00794\ V_b$	
A/C Insurance		$12.822 + 0.0013\ V_b$	
Total: Cost Varying with V_b		$22.801 + 0.0493\ V_b$	

where: C_f denotes price of fuel per U.S. gallon in dollars
W_f denotes weight of consumable fuel
T_b denotes block-to-block time in hours
V_b denotes block-to-block speed in m.p.h.

* A.T.A. formulæ modified for jet engine

Fig. 22.

regard the narrow technical definitions of efficiency are materially modified by the economic considerations of airline operation.

Although it is sometimes said that one can prove anything by generalised operating cost analysis, nevertheless, comparisons using the operating cost data of an actual airline or number of airlines should be true. Furthermore, the comparison of actual airline data with generalised formulæ apply directly to turbo-prop or turbo-jet aircraft so that adjustments have only to be made to the parts of the formulæ which deal with the engine. In the following the best available servicing and maintenance data based upon service experience has been used.

Furthermore it is desirable to compare proposed aircraft which use existing, or realistic engines, not fanciful engine schemes which may or may not materialise. Any scheme which will require 8 or 10 years to reach the standard of reliability for civil operation is not in the picture, as this is approximately the depreciation period for any new aircraft now.

In addition, to obtain a realistic picture of the operator's position one must include both direct and indirect costs.

The direct costs for reciprocating, turbo-prop, and turbo-jet aircraft are given in Fig. 22. It will be seen that in the absence of airline operation data for the jet engine, conservative figures have been used in relation to the reciprocating engine, particularly as it is now well established that the jet engine is much cheaper to maintain.

In the case of the turbo-prop there is the added complication of the airscrew and its attendant reduction gear and other controls.

A very conservative figure for the time between overhauls of 500 hours has been taken. It can confidently be expected that before the turbo-prop or turbo-jet transport is in operation on the scheduled routes, the overhaul period for the jet engine itself will be greater than this; 750 to 1,000 hours is a reasonable expectation. The large airscrews required to absorb the power of the turbo-prop will always be a liability so far as service and maintenance are concerned.

The absence of vibration so noticeable in the turbine-powered aircraft should well justify the assumption that airframe and equipment maintenance overhaul and replacement will be greatly reduced. Instrument replacement in particular will be a fraction of that on reciprocating-engined aircraft.

10.1. Fuel cost

The item of prime importance is that of fuel cost. At the moment the economy of the available jet engines which are sufficiently reliable for civil use is somewhat marginal,

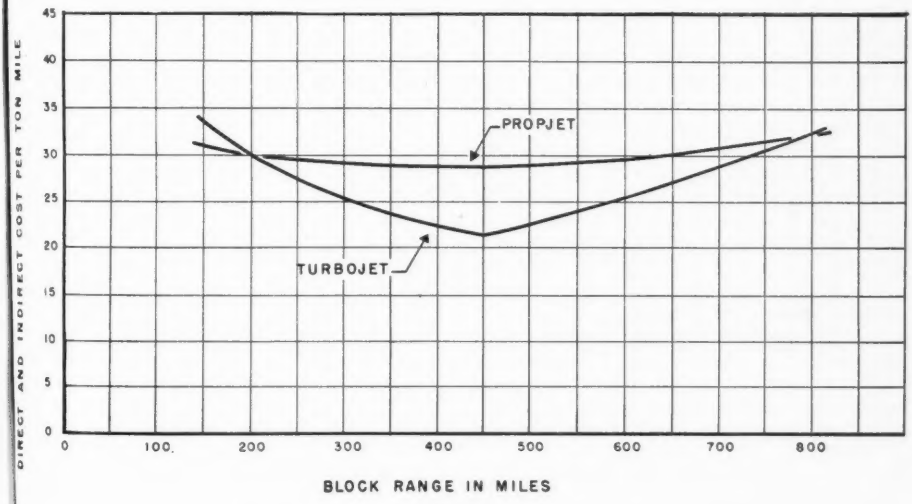


Fig. 23.
Direct and indirect operating cost per ton mile.

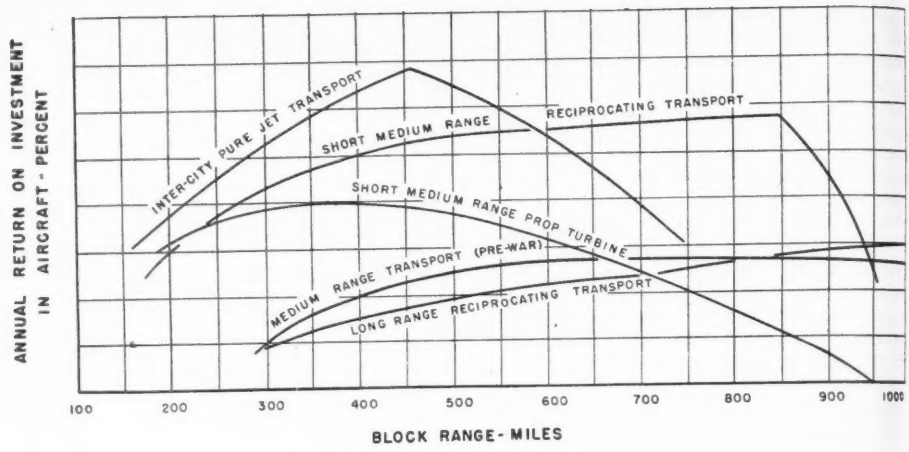


Fig. 24.
Comparative earning power.
Load factor—70 per cent. Revenue per passenger mile—5.5 cents.

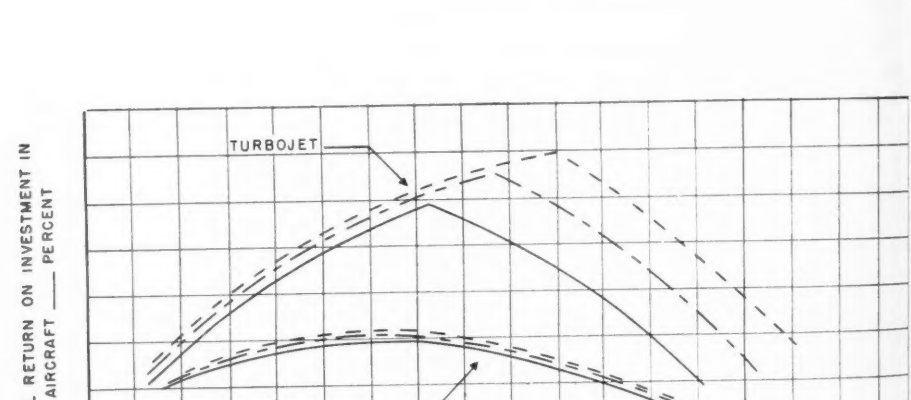


Fig. 25.
Effect of fuel consumption reduction.
—·—·— Present S.F.C.
— — — S.F.C. improved 5 per cent.
— — — S.F.C. improved 10 per cent.

and while even now the jet-powered transport has more earning power than the reciprocating-engined transport, the price of the fuel is an important factor because rather more than half the direct operating cost is due to fuel in the case of the straight-jet.

The turbo-prop is in a rather more favourable position because of its lower fuel consumption.

10.2. Direct operating costs

The foregoing comments on the various items of direct operating cost are summarised in Fig. 22 for the three types of power. This brings out the effect of the various items as estimated by the Air Transport Association formulæ. The relevant items are modified to suit the jet engine.

Comparison of these figures with actual airline operator's figures shows remarkably close agreement.

Substitution of the actual block speed values gives the curves shown in Fig. 17 for the turbo-jet and in Fig. 18 for the turbo-prop.

These show that for typical aircraft designed around available, or near available engines, the two types are roughly equal, so far as direct costs are concerned.

It is, however, necessary now to consider and add in "indirect" costs. Therefore it is necessary to examine the differences between the three types which upset the normal methods of comparison.

It is obvious that the most important difference is in the amount of fuel as a percentage of the take-off weight. This necessitates the setting up of a method of comparison between reciprocating-engined aircraft and jet aircraft which takes account of this major difference.

If one discounts the differences in refuelling which are a small part of the indirect cost, then the aircraft will be comparable and the smaller the number of aircraft in the fleet required for a given job, expressed in ton- or passenger-miles/year, the less will be the indirect cost per ton mile. An analysis of typical air routes appears to indicate that the current cost is approximately 1.75 times the direct cost, less fuel.

On this basis the combined direct and indirect costs can be estimated. These are shown in Fig. 23 and show the superiority of the jet aircraft when total airline costs are considered.

10.3. Return on investments

Another way of comparing the various types is to convert the total takings into annual return on the investment in aircraft to perform a given operation of, say, 100,000,000 ton miles/annum. Then, subtracting the total operating costs, the profit returns can be expressed as a percentage of the capital costs of the aircraft. The number of aircraft required varies with stage lengths so that for a system consisting of a number of different stage lengths a suitably weighted average number of aircraft will be required. Apart from this refinement, aircraft can be compared effectively on this basis.

Figure 24 gives the results and shows what can be expected from the various types and vintages of aircraft. It also brings out the advantages of simplicity, cheapness of fuel, and, above all, speed.

Another point which is brought out by this mode of presentation, apart from the effect of fuel cost, is the effect of improvements in engine economy. In Fig. 25 it can be seen that if the optimum earning power range of a jet transport is 460-500 miles now, then 5 per cent. improvement in fuel economy extends the optimum earning range 70 miles, while, 10 per cent. improvement will increase the optimum 140 miles with a 12 per cent. increase in return on investments. Taking the increase in range to the point of equal return then the range is increased from 460 to 730 miles, which is a 20 per cent. increase in range; so that the gains due to comparatively small improvements in fuel economy are disproportionately large. I think it will be generally admitted too that the improvements assumed are not unduly optimistic as they are already well on the way. Indeed, examination of the effect of 20 per cent. improvement in fuel economy should not be looked upon as too theoretical and is certainly well within the lifetime of the aircraft now emerging from the prototype stage.

When we turn to the prop-jet, however, similar improvements in engine performance do not have the same large effect on earning power.

The fuel being a smaller part of the direct operating costs, the effect of improvement at this time is much less. This is shown in Fig. 18 where the effect of 10 per cent. improvement in fuel consumption changes the range only 50 miles, with negligible effect on earning power.

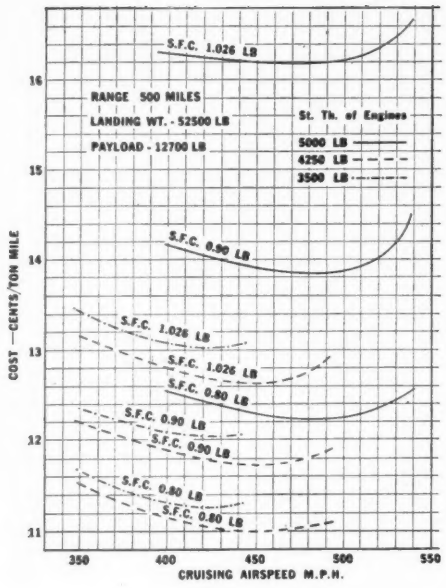


Fig. 26.

4 engine jet transport.

Cost per ton mile *versus* cruising air speed for varying engine sizes and fuel consumptions.

11. THE EFFECT OF ENGINE SIZE AND FUEL ECONOMY ON DIRECT OPERATING COSTS OF A GIVEN AEROPLANE

In view of the statements made from time to time by the casual commentator about the cruising speed at which the jet transport becomes competitive, it was thought desirable to investigate the effect of engine power and economy on direct operating costs. In this investigation it had to be assumed that the aircraft would remain of constant capacity to meet an assumed demand.

The engine sizes assumed were adopted regardless of their availability.

Another reason for this investigation was the justification of the lower cruising speeds in the 400-450 m.p.h. bracket as compared with the cruising speed of 500 m.p.h. talked about so glibly. Obviously there is in any case more justification for higher speeds and altitudes for longer range aircraft.

The result of this investigation confirmed an earlier conclusion based on a general consideration that this effect would be slight over a considerable range of speed, even with the varying size of engine required.

Let me say here and now that I am not arguing against the maximum available speed and I do not wish to be misunderstood on this point, no one would deny that the faster one can fly the better, technically and economically. I do, however, feel that it will be some time before operating speeds, in practice, are pushed up to the 500 miles an hour range. What is important is that it is quite reasonable to operate a short range jet transport at speeds appreciably below this and to obtain a perfectly reasonable operating cost. As a matter of fact, as far as direct operating costs are concerned, there is surprisingly little variation over quite a large speed range. One of the important things about having plenty of power for extra speed is not perhaps so much the speed itself, as the

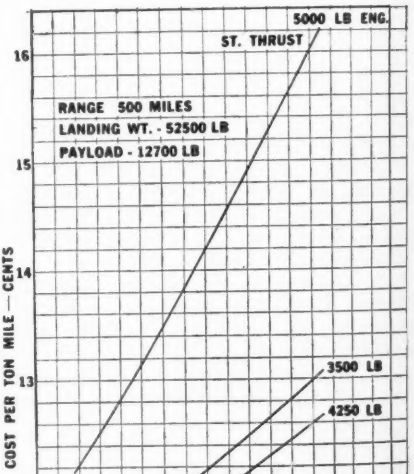


Fig. 27.

4 engine jet transport.

Minimum cost per ton mile *versus* specific fuel consumption for various engine sizes.

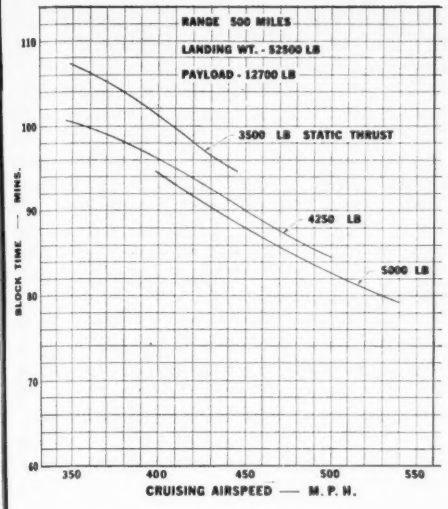


Fig. 28.

4 engine jet transport
Block time *versus* cruising air speed for various engine sizes.

excess power available for climbing rapidly to the most economical height.

Having demonstrated, therefore, that the operating costs for even, say, 400 miles an hour were reasonable it remained to see what would be the effect of improvements in fuel economy and power on the direct operating cost per ton mile for a typical jet transport. I have, therefore, prepared a number of curves which are shown in the following figures. In some ways these diagrams repeat themselves as they show somewhat similar results in different ways. Nevertheless, I hope they will bring out the various points.

In Fig. 26 are plotted the effect of three specific fuel consumption figures and three engine thrust figures on the performance of an aircraft of approximately the same size and all-up weight. Slight adjustments were made for the varying weights of the wing and power plants. The first thing concluded from this chart is that for a given specific fuel consumption there is an optimum engine size which in this case is about 4,000 lb. static thrust. Having achieved this, the only other worthwhile gain is that in fuel economy. Furthermore the variation of cost per ton mile with forward speed for a given range is comparatively negligible. The one thing that does happen is that the speed range is pushed over towards the high speed end as the thrust is increased. Of the three fuel consumptions quoted, slightly over one has, of course, been achieved. The .9 is a realistic next step and .8 is somewhat off in the future and rather optimistic, at any rate as far as civil transports are concerned.

Figure 27 shows in a different way the same result. In this case minimum operating costs are plotted against fuel consumption for given engine sizes. This also brings out the fact that the optimum engine size is very near the middle of the three engine sizes examined.

Figure 28 in this group indicates the one clear advantage of increased power, that of

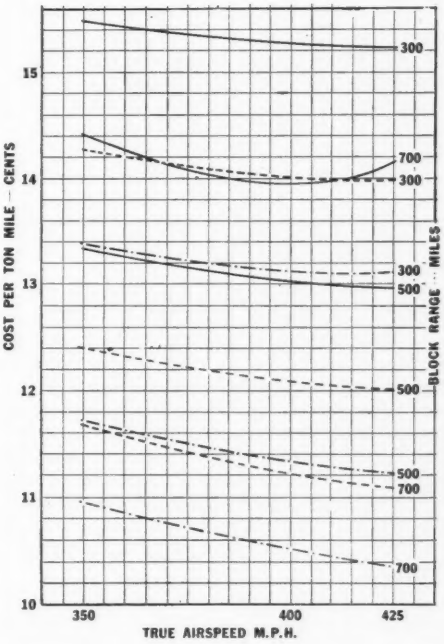


Fig. 29.

Static thrust per engine = 3,500 lb.
Maximum take-off weight = 60,000 lb.
Maximum payload = 12,700 lb.
Legend specifications:
1.026 ————————
.90 - - - - - - - - - -
.80 —·—·—·—·—
Direct operating costs *versus* cruising speed at 30,000 feet.

reduced block to block time. This, while not affecting direct operating costs because of the balance between the cost of the extra fuel used and the time saved, should reflect itself in the indirect operating costs and thereby result in a further saving in overall cost which has not been allowed for in these comparisons.

Figure 29 shows the effect of cruising speed on direct operating costs for three ranges and three fuel consumptions. Here again the optimum range is indicated at about 500 miles for this particular aeroplane on the higher consumption figure. This apparently is true for all cases and the main point is the direct saving due to the improved fuel economy.

12. CONCLUSIONS

The turbine-propeller and turbine-jet aircraft which are now in the prototype stage and represent the next breed of civil transports, even under present operating conditions, are economically competitive with current types. With the improvement of the jet engine this advantage will be greatly increased. The turbine-jet aircraft stands to gain relatively more than other types by advances in engine fuel economy and offers the greater scope for development over the next few years.

The full and complete replacement of the present and current types of inter-city and medium range aircraft by the turbo-prop and turbo-jet aircraft of the near future, requires the introduction of novel methods of airline and aerodrome traffic control. This has lagged sadly behind aeroplane development and, while the new types are just around the corner, the traffic control authorities and aeronautics administration authorities both in the U.S.A., England, and Canada are only just beginning to face up to the problems involved.

Both for this reason and also, because it must be so with all new equipment, there will be a period of operational experiment preparatory to the full scheduled operation of the jet transport.

In this phase the Empire air routes are, if not uniquely, at any rate particularly, suitable for this development period.

As far as the preponderant internal inter-city systems are concerned, the distances and weather are suitable. In addition the basic simplicity of the systems obviates distracting complications. The absence of frequent international frontiers, the language problems, and the stacking problem are important factors. Canada and Australia are particularly favourable in these regards, compared with Europe.

The rapidly developing members of the Commonwealth therefore can play a significant part in this new and revolutionary phase in air transport development, and indeed in all branches of aeronautical development.

It is a place in which the youth and enthusiasm of the autonomous members of the Commonwealth can contribute vitally and with pride.

13. ACKNOWLEDGMENTS

I should like to express my thanks to A. V. Roe Canada Limited for permission to give this paper and also my appreciation to members of that firm for the assistance which I have had in preparation of this paper from the Sales and Service Department and the Aerodynamics Department of the Airframe Design Division. My thanks are particularly due to Mr. T. G. Dunkin for his work in preparing the charts and diagrams.

REFERENCES

1. BAIN, J. T. Aircraft and The Airlines—A Canadian View. Third British Commonwealth and Empire Lecture, 1947. JOURNAL R.Ae.S. April 1948.
2. MASEFIELD, P. G. Some Economic Factors in Civil Aviation. Fourth British Commonwealth and Empire Lecture, 1948. JOURNAL R.Ae.S. October 1948.
3. HETZEL, E. Emergency Operation of Turbo-jet Transports. *Aero Digest,* June 1949.
4. ATKIN, E. H. The Case for the Medium Range Jet Transport. Institute of Aeronautical Sciences Lecture, May 1948, at New York (unpublished).

VOTE OF THANKS

A vote of thanks to Mr. Atkin was proposed by P. G. Masefield, Esq., M.A., F.R.Ae.S.

Mr. Masefield: On the occasion of the delivery of the British Commonwealth and Empire lectures, the Royal Aeronautical Society had the opportunity and privilege of drawing together aeronautical personages from the whole Common-

wealth, just as the Commonwealth itself was drawn together by Aviation. The occasion of Mr. Atkin's lecture was notable in that it had gathered together all the past Commonwealth and Empire lecturers, with the exception of Sir Henry Self, who had been short-circuited into electricity! It was pleasing indeed to see Mr. Hudson Fysh, who was the prototype lecturer, and Mr. J. T. Bain, of Canada, and to welcome with them so many Commonwealth representatives.

The fifth lecturer in the series was the second from Canada, and Edgar Atkin had shown that that great Dominion had kept in the forefront of thinking in aircraft development; and not only in thinking. He had been privileged to know Edgar Atkin for a number of years and to watch the practical proof of his faith in jet transports taking shape from merely a gleam in his eye to the interesting Avro C-102. Mr. Atkin's lucidity as a lecturer was matched only by his nobility of nature; he recalled having been one of a party who had arrived at the airport at Toronto at 4 o'clock on an extremely cold morning, and even at that early hour Mr. Atkin had been there, with his famous smile, to meet them. That was the quintescence of hospitality.

It was a particular pleasure to propose the vote of thanks, not only because he himself had been put on the same spot a year ago, but also because, being in the position of a gamekeeper turned poacher, he was now directly concerned with some of the routes which Mr. Atkin had illustrated on the screen.

The lecturer had pointed out that, like the Campbells, the turbines were coming. But the argument continued to revolve around the question whether the future transport aircraft should just squirt out air at the back or should revolve propeller blades as well. Had there been an opportunity for discussion of the lecture he would be sorely tempted to enter the lists, for as a representative of an organisation which had already put its money on propellers, and hoped to get that money back, he would like to discuss one or two points. Perhaps some of the galaxy of designers who were present would also like to joint in the discussion!

It was refreshing, from the operator's point of view, to find a designer making such play with economics. He had been interested in Mr. Atkin's analysis of length of routes and the importance of matching the size of the aircraft to stage length; that was absolutely vital. In that connection some of them had concluded that the piston engine showed up fairly well on the relatively short haul, then the propeller-turbine had its place on the intermediate length routes, followed by the plain jet for the longer range. But Mr. Atkin had firmly suggested that the trials for the turbo-jet should be in Australia.

Apart from such controversial points, he was glad that Mr. Atkin had emphasised the importance of speed; it was enormously important from the operators' point of view. Again, he was right to stress the vital importance of air traffic control; there was a tendency in some quarters still to ignore the fact that satisfactory air traffic control was a fundamental link in the whole chain of successful and economic turbine aircraft operations, whether the aircraft used plain jets or propeller jets. He felt that those who even now passed lightly over the problem of air traffic control, were rather like that "Perfect Reactionary" who had remarked:—

"As I was sitting on my chair,
I knew the bottom was not there,
Nor legs, nor back; but I just sat,
Ignoring litttle things like that."

Mr. Atkin, however, did not ignore "little things like that."

Many who had to operate aeroplanes, as well as those who had to design aeroplanes, would study the lecture carefully and, he sincerely hoped, would profit by it, in the literal sense. It was a great pleasure to propose a vote of thanks to Mr. Atkin for the fifth British Commonwealth and Empire lecture.

The President claimed the privilege of seconding the vote of thanks, which was warmly accorded.

COUNCIL DINNER

Following the Lecture a dinner was given by the Council of the Society at 4 Hamilton Place, at which the following were present:—

E. H. Atkin, Esq., F.R.Ae.S., Lecturer.

J. T. Bain, Esq., Director of Engineering and Maintenance, Trans-Canada Air Lines; R. H. Belcher, Esq., representing Secretary of State for Commonwealth Relations; W. J. Bigg, Esq., C.M.G., representing the Secretary of State for the Colonies; Sir John S. Buchanan, C.B.E., F.R.Ae.S., President, Royal Aeronautical Society; Major G. P. Bulman, C.B.E., B.Sc., F.R.Ae.S., Council Member.

Group Captain C. Clarkson, F.R.Ae.S., British Civil Air Attaché in Washington; A. V. Cleaver, Esq., A.R.Ae.S., Council Member; Air Marshal Sir W. Alec Coryton, K.B.E., C.B., M.V.O., D.F.C., Controller of Supplies (Air) Ministry of Supply; Dr. H. Roxbee Cox, D.I.C., B.Sc., F.R.Ae.S., Past President.

Dr. G. P. Douglas, O.B.E., M.C., F.R.Ae.S., Council Member; G. H. Dowty, Esq., F.R.Ae.S., Chairman and Managing Director of Dowty Equipment Ltd.; Ivan H. Driggs, F.R.Ae.S., Bureau of Aeronautics, U.S. Navy Department; Squadron Leader S. J. Dastur, R.I.A.F., Assistant Air Adviser to the High Commissioner for India.

G. R. Edwards, Esq., M.B.E., B.Sc., F.R.Ae.S., Council Member; Lt. General J. F. Evetts, Director, British Ministry of Supply Mission in Australia.

W. S. Farren, Esq., C.B.E., F.R.S., F.R.Ae.S., Council Member; Sir A. H. Roy Fedden, M.B.E., D.Sc., Hon. F.I.Ae.S., F.R.Ae.S., Past President; W. Hudson Fysh, Esq., D.F.C., A.F.R.Ae.S., Managing Director, Qantas Empire Airways, Sir Arthur Gouge, B.Sc., F.R.Ae.S., Past President.

G. Haldeman, Esq., Director of Air Services of the Civil Aeronautics Administration of U.S.A.; Professor A. A. Hall, M.A., F.R.Ae.S., Council Member; S. Scott Hall, Esq., M.Sc., D.I.C., F.R.Ae.S., Council Member; Professor N. J. Hoff, F.R.Ae.S., Professor of Aeronautical Engineering, Brooklyn Polytechnic.

G. S. Lindgren, Esq., M.P., Parliamentary Secretary to the Ministry of Civil Aviation.

Brigadier General Sir H. Osborne Mance, K.B.E., C.B., C.M.G., D.S.O., President-Elect, Institute of Transport; P. G. Masefield, Esq., M.A., F.R.Ae.S., Council Member.

Sir Frederick Handley Page, C.B.E., F.R.Ae.S., Past President; W. G. A. Perring, Esq., F.R.Ae.S., Vice-President; C. M. Poulsen, Esq., Past Editor of *Flight*; Captain J. Laurence Pritchard, Hon.F.I.Ae.S., Hon.F.R.Ae.S., Secretary, Royal Aeronautical Society.

Group Captain M. Rabb, Air Adviser to the High Commissioner for Pakistan; N. E. Rowe, Esq., C.B.E., B.Sc., D.I.C., F.R.Ae.S., Vice-President; Sir Archibald Rowlands, G.C.B., M.B.E., Permanent Secretary, Ministry of Supply.

R. M. Seymour, Esq., Civil Aviation Liaison Officer, Australia House; G. Slack, Esq., South African Airways Representative, London; Air Commodore Whitney Straight, C.B.E., M.C., D.F.C., Managing Director and Chief Executive, British Overseas Airways Corporation.

Wing Commander K. W. Trigance, D.F.C., representative of the High Commissioner for New Zealand; Group Captain G. G. Truscott, O.B.E., Director of Aircraft Maintenance, Department of National Defence for Air (Canada); J. H. Tudhope, Esq., Canadian Government Representative on Civil Aviation, London; W. Tye, Esq., O.B.E., B.Sc., F.R.Ae.S. Council Member.

Captain C. F. Uwins, A.F.C., O.B.E., F.R.Ae.S., Honorary Treasurer, Royal Aeronautical Society.

Dr. H. C. Watts, M.B.E., F.R.Ae.S., Vice-President; John A. Wilson, Esq., Former Director of Civil Aviation, Canada; L. A. Wingfield, Esq., M.C., D.F.C., A.R.Ae.S., Solicitor, Royal Aeronautical Society.

THE DESIGN OF COMPRESSION STRUCTURES FOR MINIMUM WEIGHT

by

D. J. FARRAR, M.A., A.F.R.Ae.S.

1. INTRODUCTION

1.1. Fundamental importance of the problem

The primary structure of an aeroplane usually consists basically of a set of tubular beams. The main structural box of the wing or tailplane is a well-known example: a semi-monocoque fuselage is another. For any given loading condition of the aircraft the material in the tube is stressed mainly in tension, in shear, or in compression, depending on its location in the tube cross section.

The aim of the designer is to make the material fulfil these three functions in the most economical manner. In tension, he is limited only by the quality of material available. In shear, this is again substantially the case, although it is well known that very light shear webs over great depths do not develop as high an effective failing stress as do more sturdy webs. This property of dependence on the *intensity of loading* is much more marked in the case of the compression structure, which is liable to instability in various ways.

The fundamental problem of the design of such a structural element is the stabilising of the compression surface. The ingenuity of the designer in this respect has led to various types of structure being adopted: one may mention the two-spar wing box, the thick skins reinforced by stringers and supported by ribs in the case of a wing, or by frames in the case of a fuselage, and the sandwich structure. It is clear that a generalised approach cannot cover all forms of structure, and in the present case the second type only is considered.

Paper received March 1949.

Mr. Farrar is Assistant Chief Designer, Aircraft Division, Bristol Aeroplane Co. Ltd.

1.2. Type of structure considered

It is assumed that it is required to design a surface carrying a certain ultimate compressive end load. The surface consists of a skin stiffened by longitudinal stringers, and supported at intervals by ribs or frames.

As a limiting case this type of structure can include the two-spar wing, in which there are only two "stringers" which are stabilised by the spar webs. The trend of modern design has been towards the thick stiffened skin type of construction, the thick skin being needed for torsional stiffness in the case of the wings or tailplanes and for carrying pressurising loads in the case of fuselages. In addition to the reinforced skin cover there may also be spar booms which carry part of the end load.

1.3. Aims of the investigation

Of the various design conditions, the one of over-riding importance is that the structure should have adequate strength. The primary purpose of this investigation therefore is to determine the structure which has a minimum weight when its external dimensions and its strength are given.

In general the design conditions often involve other aspects besides strength. The provision of adequate stiffness may be one: ease of manufacture, and limitation of working stresses by fatigue considerations, may be others: they are not inevitable design conditions, whereas strength considerations are.

A means is therefore provided for assessing the effect of geometrical limitations which may be imposed by these other requirements on the structural weight, so that a structure can be chosen in which the weight increase, above that necessary for strength alone in the minimum weight structure, is also a minimum.

1.4. Limitations and difficulties

In a subject with so broad a scope it is inevitable that any solution involving a reasonable amount of labour is not a precise and complete one: in fact it may be assumed to be a design condition of the structure that the labour involved in design should not be prohibitive. Some reasonable limits to the range of the problem explored, and perhaps to the accuracy of the answer desired, must therefore be set.

To illustrate this point, one may note that it is necessary to include many forms of stringers so as to pick the best type for the particular structure—typical shapes being Z-section, top hat, bulb angle, and so on. A certain amount of experience is necessary in order to choose a limited range of sections which must be subjected to theoretical analysis. Even when a basic type such as the Z-section has been chosen, there are several shape parameters which can be widely varied.

When a single shape of stringer has been chosen for analysis, the situation is still far from favourable on the theoretical side. The various modes of instability are often quite heavily coupled so that analysis is difficult and depends on a large number of parameters: the failing stress may be appreciably different from the instability stress because of initial eccentricity or lateral air loading, and so on.

In view of these difficulties one may feel that it is not possible to find an optimum structure. However, the nature of an optimum is such that the weight is a mathematical minimum with respect to the design parameters: it follows therefore that if our methods of analysis provide only a reasonable approximation to the truth, the weight will still be very close to the mathematical minimum achieved by the ideal structure.

1.5. Division of the problem

Let us suppose that the compression skin-stringer combination is required to carry an end load P per unit width, and that the ribs or frames are uniformly spaced at a distance L apart along the length of the structure.

If we fix P and L, and assume that the ribs or frames possess a certain minimum stiffness, we must first determine the lightest skin-stringer combination which can carry the loading P over the bay length L. This is the first stage in the analysis: and if the spacing of the ribs or frames is completely dictated by practical considerations, one need go no farther.

In a structure of fair size it is generally possible to vary the rib or frame spacing. The second stage of the problem is then to vary the rib or frame spacing so that the total weight (ribs + skin + stringers) is a minimum.

2. CHARACTERISTICS OF THE SKIN-STRINGER COMBINATION

2.1. Conditions assumed

It is assumed that the number of stringers is sufficiently large for the instability stresses to be the same as in an infinitely wide panel (more than three or four stringers usually ensures that this is so). The ribs are assumed to supply simple support so that the combination of skin and stringers acts as a pin-ended strut of length L.

NOTATION

P = compressive end load carried per inch width of skin-stringer combination.
L = rib or frame spacing.
T = thickness of skin which has the same cross sectional area as the skin-stringer combination.
E = compression Young's modulus of skin-stringer material.
E_T = tangent modulus of skin-stringer material.
K = radius of gyration of skin-stringer combination.
f = mean stress realised by skin and stringers at failure. (Note: $f = P/T$).
d = flange width of stringer.
h = depth of stringer.
b = stringer spacing.
t_s = stringer wall thickness.
t = skin thickness.
A_s = cross sectional area of stringer.
$f_o = 3.62\,E\,(t/b)^2$.
f_b = initial local buckling stress.
f_L = secondary local buckling stress in stringer.
f_T = secondary torsional buckling stress in stringer.
D = depth of rib.
T_R = thickness of an ideal plate rib which has the same weight as the actual rib.
W = weight of skin-stringer combination per unit area.

THE ROYAL AERONAUTICAL SOCIETY
GRADUATE AND STUDENT SECTION

November 1949

THE EXTRAORDINARY GENERAL MEETING

An Extraordinary General Meeting of the Section was held in the Council Room of the Society on Wednesday, 5th October 1949, at 7.30 p.m. The Section Chairman, Mr. J. W. F. Housego, was in the Chair.

AGENDA. 1. To receive the Hon. Secretary's Report of the activities of the Section during the period March to September 1949.
2. To receive a report on the decisions of Council on the Section.
3. To discuss any other business.

1. The Chairman explained that Council's decision to make the Section Committee a Committee of Council had necessitated a General Meeting to appoint the Section's six representatives.

The Hon. Secretary then read his Report (which is attached to this summary), and this was adopted.

2. A report of the events leading to Council's decision to form a Graduates' and Students' Committee of Council was given by the Chairman. Council had appointed its three representatives, but the six representatives of the Section had still to be chosen. The Chairman read a resolution of the retiring Committee, which recommended to the Section that, in order to ensure continuity, the six members should be chosen from the retiring Committee. Mr. Ewart suggested that not more than one member should be from any single firm or College. Nominations were then received, and the election was held.

The new Graduates' and Students' Committee of Council for the period October 1949 to March/April 1950 would therefore be:—

COUNCIL'S REPRESENTATIVES: S. SCOTT HALL, *Fellow* (P.D.T.D.(A), M.O.S.), A. V. CLEAVER, *Associate* (de Havilland Engine Co. Ltd), J. W. F. HOUSEGO, *Graduate* (Handley Page Ltd.).

THE SECTION'S REPRESENTATIVES: M. K. BOWDEN, *Student* (Northampton Engineering College), M. C. CAMPION, *Graduate* (Bristol Aeroplane Co. Ltd.), P. T. FINK, *Graduate* (Imperial College), J. C. GIBBINGS, *Graduate* (Queen Mary College), J. G. ROXBURGH, *Graduate* (Handley Page (Reading) Ltd.), A. STANBROOK, *Student* (Fairey Aviation Co. Ltd.).

The Meeting adopted resolutions that the new Committee should recommend to Council that the number of the Section's representatives should be increased to twelve (to allow a greater number of organisations to have members on the Committee), and should consider the possibility of the Officers of the Section being elected as such, and not merely as Committee members.

3(*a*) Mr. Bowden reported the progress of the scheme for publishing a series of pamphlets on the application of aeronautical theory to practical aircraft design. This scheme had been discussed by the Committee, which felt that the gap would be narrowed between the scope of the University text books and design practice. It was hoped that an experienced engineer could be appointed to edit the series, and that the individual papers would be written by members of the Industry who were working on the particular subjects. The Committee had recommended to Council that such a scheme should be adopted, and the Chairman moved the ratification of the Committee's actions. This was carried unanimously.

(*b*) Mr. Gibbings asked whether the Society's new "Section Lectures" would be of the same type and standard as those of the Section. The Chairman thought that the description printed in the lecture card was ambiguous, as these lectures were to be of an advanced technical standard and were intended for specialists in the various subjects. He did not think they would take the place of the Section's lectures.

HON. SECRETARY'S REPORT—MARCH TO SEPTEMBER 1949

SUMMARY

In the six months since the last General Meeting of the Section, 23rd March 1949, four technical meetings were held, which were attended by an average of 50 persons. Three visits were arranged, of which one had to be cancelled. The Committee met seven times to administer the Section's affairs.

A number of articles describing the training schemes operated in various parts of the country, and a number of technical papers by Graduates and Students were published in the Section's pages in the JOURNAL. Mr. Bowden was appointed Hon. Editor of the Section's pages of the JOURNAL.

COMMITTEE 1949-1950

Chairman: J. W. F. HOUSEGO, *Graduate* (Handley Page Ltd.)

Vice-Chairman: P. T. FINK, *Graduate* (Imperial College)

Hon. Secretary: M. C. CAMPION, *Graduate* (Vickers-Armstrongs Ltd.)

Assistant Hon. Secretary: D. A. THURGOOD, *Student* (Vickers-Armstrongs Ltd.)

Committee: M. K. BOWDEN, *Student* (Northampton Engineering College), W. M. BRADY, *Graduate* (Vickers-Armstrongs Ltd.), J. C. GIBBINGS, *Graduate* (Queen Mary College), F. G. IRVING, *Graduate* (Imperial College), J. R. MILLER, *Graduate* (Hawker Aircraft Ltd.), J. K. PUDNEY, *Student* (Fairey Aviation Co.), J. G. ROXBURGH, *Graduate* (Handley Page (Reading) Ltd.), A. STANBROOK, *Student* (Fairey Aviation Co.).

TECHNICAL MEETINGS

The Meetings held since March 1949 were:—

6th April 1949. The Trend of Jet Engine Development, by A. A. Lombard, A.F.R.Ae.S. (Attendance 74.)

19th April 1949. The Meaning and Measurement of Stability Derivatives, by P. T. Fink, Grad.R.Ae.S. (Attendance 41.)

3rd May 1949. Notes on Fighter Development, 1936-1948, by J. K. Quill, Esq. (Attendance 41.)

13th May 1949. Pressure Cabins, by D. Cardwell, A.F.R.Ae.S. (Attendance 47.)

Five Lectures had been arranged for the Autumn Session. The first would be an address by the President, and another would be by a Member of the Section. It was hoped that a number of Lectures would be delivered by Graduates and Students in the Spring Session of 1950, and negotiations were in hand for a joint meeting with the London Graduates' Section of the Institution of Mechanical Engineers and the London Students' Section of the Institution of Electrical Engineers.

VISITS

The following visits were made by members during the summer:—
Saturday, 18th June 1949. Croydon Airport. (Attended by 8 persons.)
Saturday, 10th September 1949. London Airport. (Attended by 18 persons.)

A visit to High Duty Alloys Ltd., Slough, arranged for Wednesday, 10th August, was cancelled because of the lack of applicants.

A visit to the National Physical Laboratory, Teddington, was arranged for Saturday, 19th November 1949.

SOCIAL ACTIVITIES

Arrangements had been made for an Informal Reception and Conversazione for members of the Section and their friends, to be held at the Society on Friday, 21st October 1949.

(*Signed*) MICHAEL C. CAMPION

October 1949. Hon. Secretary, Graduate and Student Section.

REPORT ON COUNCIL'S DECISIONS REGARDING THE SECTION

In November 1948 certain criticisms of the Graduate and Student Section were made to Council, resulting in the formation by Council of an *ad hoc* Committee to investigate the Section's affairs, and to recommend means of improving the Section.

The *ad hoc* Committee submitted its report to Council on 28th July 1949 as a result of which, the following decision was made by Council:—

> "That the Graduates' and Students' Committee should become a Committee of Council and should consist of nine members. Three of these should be elected by the Council of the Society. . . . Six members of the Committee should be elected by the Graduates and Students of the Society."

Council appointed to the Committee, Mr. S. Scott Hall and Mr. A. V. Cleaver (who, together with the late Mr. E. J. N. Archbold, had served on the *ad hoc* Committee) and Mr. J. W. F. Housego, the Graduate member of Council.

2.2. General case[1]

Consider a skin-stringer combination which is equivalent in area to a skin of thickness T. Let the radius of gyration of the combination be K.

Then if the mean compressive stress in the skin and stringers is f,

$$P = fT \quad . \quad . \quad . \quad (1)$$

Euler instability of the combination is given by

$$f = \frac{\pi^2 E_T K^2}{L^2} \quad . \quad . \quad (2)$$

where E_T is the tangent Young's modulus of the material. Since the skin-stringer combination can be regarded as an assembly of interconnected plates, it will also develop instability of a local plate-buckling type. The mean stress at which this local instability occurs is given by

$$f = AE_T (T/K)^2 \quad . \quad . \quad (3)$$

where A is a constant depending on the geometry of the cross section. There may be several modes of local buckling; we will assume that the one to which A is appropriate will involve distortions of the section sufficiently large to induce premature flexural instability and failure.

It is easily demonstrated that the lightest structure is that in which flexural instability and local instability coincide. If we impose this condition we find that

$$f = \pi^{\frac{1}{3}} A^{\frac{1}{3}} \left(\frac{PE_T}{L}\right)^{\frac{2}{3}} \quad . \quad . \quad (4)$$

Now the coefficient A depends on the type of skin-stringer combination chosen, and for the optimum structure will have a maximum value. If we call this maximum value A_o, then the highest stress which could ever be achieved is given by

$$f_o = \pi^{\frac{1}{3}} A_o^{\frac{1}{3}} \left(\frac{PE_T}{L}\right)^{\frac{2}{3}} \quad . \quad (5)$$

The implication of this result is an important one: it is that the maximum stress which could possibly be achieved is dictated entirely by the value of the structure loading coefficient P/L, which is the fundamental quantity dictating the weight of the skin-stringer combination. It is thus economic to make P as large as possible by concentrating all the compression material in the sheet-stringer cover, and almost eliminating spar booms.

In seeking to determine the best type of skin-stringer combination, we must determine the best value of A which each can achieve. At this stage the analysis becomes more detailed since a variety of types must be considered and the individual instability stresses must be explored for each type over a range of geometrical parameters. Once the value of A_o has been determined, families of optimum structures can immediately be produced for all P and all L, so that the actual design process is extremely rapid once the general investigation is completed. As a specific example here we consider the case of Z-section stringers, which are widely used.

2.3. Instability characteristics of Z-section stringers

The Z-section stringer-skin combination can develop several separate types of instability, which may be coupled to a greater or less degree.

(*a*) *Skin buckling* (or initial buckling). This generally involves waving of the skin between stringers in a half-wavelength comparable with the stringer pitch. There will also be a certain amount of waving of the stringer web and lateral displacement of the free flange. For some proportions these latter may become larger than the skin displacements, and the mode becomes more torsional or local in nature (*see* (*b*) and (*c*)).

(*b*) *Local instability.* A secondary short-wavelength buckling may take place in which the stringer web and flange are displaced out of their own planes in a half-wavelength comparable with the stringer depth. There will be smaller associated movements of the skin and lateral displacements of the stringer free flange.

(*c*) *Torsional instability.* The stringer rotates as a solid body about a longitudinal axis in the plane of the skin, with associated smaller displacements of the skin normal to its plane and distortions of the stringer cross-section. The half-wavelength is usually of the order of three times the stringer pitch.

(*d*) *Flexural instability.* Simple strut instability of the skin-stringer combination in a direction normal to the plane of the skin. There may be small associated twisting of the stringers. The half-wavelength is generally equal to the frame spacing.

(*e*) *Inter-rivet buckling.* Buckling of the skin as a short strut between rivets: this can be avoided by using a sufficiently close rivet pitching along the stringer.

(*f*) *Wrinkling.* A mode of instability similar to inter-rivet buckling, but analogous

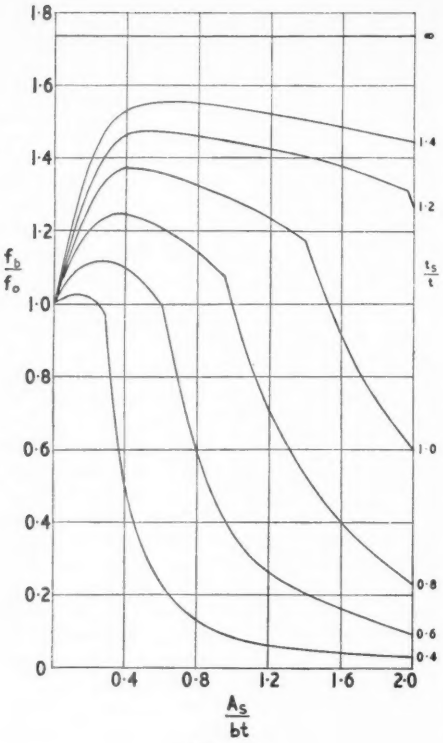


Fig. 1.
Initial buckling stress of flat panels with Z-section stringers ($d/h=0.3$).

to wrinkling of a sandwich structure, in which the skin develops short-wavelength buckling as an elastically supported strut. For all practical skin-stringer combinations it can be avoided by keeping the line of attachment very close to the stringer web.

2.4. Failure of Z-section stringers

When the skin-stringer combination approaches its Euler instability stress, development of instabilities (*a*), (*b*), (*c*), (*e*) or (*f*) will so reduce the flexural stiffness as to cause premature collapse.

If the Euler instability stress is reasonably remote, instability (*a*) (skin buckling) will not precipitate failure, and the structure will carry increased load, with the skin buckled, until failure occurs by the onset of instability (*b*), (*c*), (*e*) or (*f*). In general an excessive margin of flexural stiffness is needed to prevent failure due to any of these latter four modes.

We will therefore consider, separately, two cases. In the first, primary local buckling causes flexural failure. In the second, skin buckling develops and flexural failure is precipitated by secondary local buckling. It will be assumed that inter-rivet buckling and wrinkling are avoided by suitable disposition of the riveting.

3. Z-SECTION STRINGERS—INITIAL LOCAL BUCKLING CAUSING FAILURE[2]

3.1. Initial local buckling

The local buckling mode which is the first to develop is a mixture of modes (*a*), (*b*) and (*c*) of Section 2.3, the predominant type of buckling being dictated by the geometry of the particular skin-stringer combination used.

The stress at which this initial buckling occurs has been determined theoretically by J. H. Argyris[3] for a wide range of skin-stringer combinations, allowance being made for all the inter-actions between the various modes of distortion. Typical results are shown in Fig. 1 in which the non-dimensional buckling stress (f_b/f_o) is plotted against A_s/bt for various values of t_s/t. (*Note*: f_o is the buckling stress of the skin if pin-edged along the stringers, and f_b the actual initial buckling stress.)

The upper portions of the curves correspond to a skin-buckling-cum-stringer local type of instability, while the lower portions of the curves correspond to a stringer torsional-cum-lateral type of instability over a longer wavelength. The change of slope in the curves takes place when these two types of initial buckling occur at the same stress.

3.2. Flexural instability

Considering a stringer associated with a pitch b of skin, the whole cross section is fully effective until initial local buckling occurs.

In general the stringer will not develop pure flexural instability: there will also be a certain amount of stringer twisting, the analysis of which is far from simple. Fortunately the type of design which this analysis will show to be most efficient is one in which flexural-torsional coupling is small, and we will therefore assume that pure flexural instability occurs. If we consider $d/h=0.3$, the second moment of area of the skin-stringer combination is

$$I_{NA} = \frac{0.633bt + 0.37ht_s}{1.6ht_s + bt} h^2 t_s \quad . \quad (6)$$

The flexural instability stress is therefore

$$f_E = \frac{\pi^2 E_T}{L^2} \times h^2 t_s \times \frac{0.633bt + 0.37ht_s}{(1.6ht_s + bt)^2} \quad (7)$$

We equate this to the initial local buckling stress

$$f_b = f_b / f_o \times 3.62 E_T (t/b)^2 \quad . \quad (8)$$

The load per inch run is then given by

$$P = ft\left(1 + \frac{1.6ht_s}{bt}\right) . \quad . \quad (9)$$

where $f = f_E = f_B$.

Combining equations (7), (8), (9) in the same manner as equations (1), (2), (3) we find

$$f = F\sqrt{\frac{PE_T}{L}} \quad . \quad . \quad (10)$$

where F is a function of A_s/bt and t_s/t, corresponding to the quantity $\pi^4 A^4$ of equation (4); it is a measure of the structural efficiency of the skin-stringer combination.

3.3. Optimum structure

The quantity $F\left(=f\sqrt{\frac{L}{PE_T}}\right)$ is plotted against A_s/bt and t_s/t in Fig. 2.

It is seen that an optimum value of A_s/bt and t_s/t exists, at which for a given P, E_T and L the stress realised will be a maximum. For this optimum design with $A_s/bt = 1.5$ and $t_s/t = 1.05$ we can write

$$f = 0.95\sqrt{\frac{PE_T}{L}} \quad . \quad . \quad (11)$$

It is also noticeable that a ridge of high realised stress exists for the family of designs where the two types of local buckling occur simultaneously; if for any reason the minimum-weight design cannot be used, it is economic to use designs of this family. (The general principle seems to emerge that the most efficient designs are those in which failure occurs simultaneously in all possible buckling modes.)

3.4. Design charts

If we consider only the more efficient designs, in which the two modes of local buckling occur at the same stress, the results can be presented in the form of Fig. 3.

From these curves the stress realised by a given type of structure, together with the stringer pitch and depth, and the skin and stringer thicknesses, may be found at once for any basic design conditions P, E_T and L.

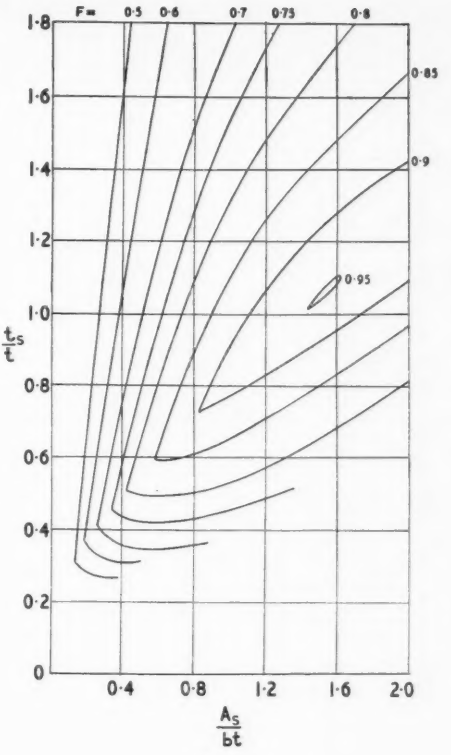


Fig.2.

Contours of $f\sqrt{\frac{L}{PE_T}}$ for Z-section stringers where initial buckling coincides with failure.

A useful feature now becomes apparent: if for any reason it is not possible to use the minimum-weight design, Fig. 3 shows the amount of weight penalty incurred. For example, if practical considerations demand that $b\left(\frac{E_T}{PL^3}\right)^{\frac{1}{4}}$ cannot be less than 2.0, the weight of the structure will inevitably be 21 per cent. greater than the lightest possible. If $b\left(\frac{E_T}{PL^3}\right)^{\frac{1}{4}}$ could be reduced to 1.5, the increase would only be 9 per cent.

Thus the efficiency of the structure from a weight point of view can be related quantitatively to geometrical limitations imposed by consideration of ease of manufacture, stiffness, ease of maintenance and so forth, and with such a quantitative relationship a

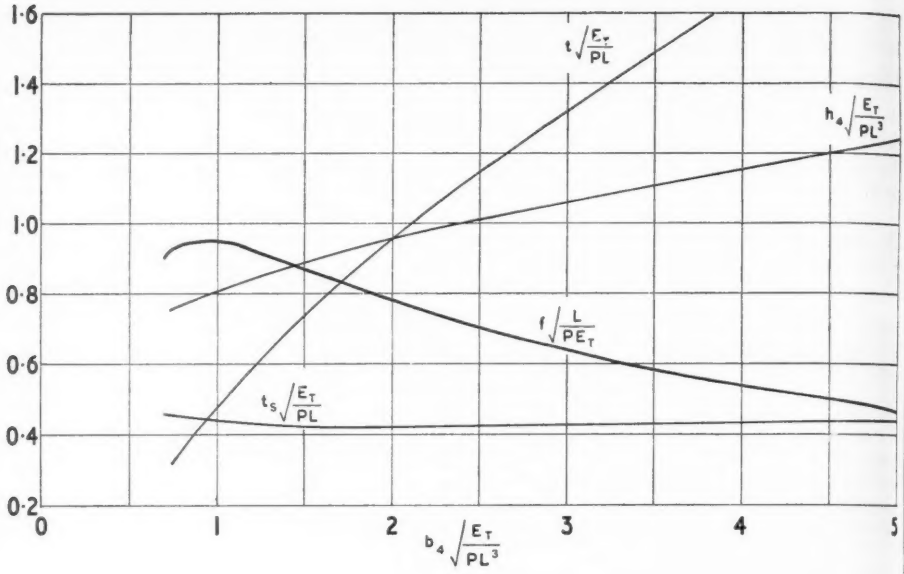


Fig. 3.
Design chart for optimum Z-section stringers where initial buckling coincides with failure.

compromise is more readily found in which allowance is made for all the various design conditions.

3.5. Effect of initial eccentricity

In practice the full theoretical value of $F\left(=f\sqrt{\frac{L}{PE_T}}\right)$ is not achieved: experimental results indicate that about 90 per cent. is an average realised value. This reduction is due to the effect of initial eccentricity of the structure, and (unlike the case of a simple strut) it occurs even at low design stresses.

Suppose that the Euler stress and skin buckling stress of a particular skin-stringer combination are both 30,000 lb./in.^{2}. When an actual compressive stress of 27,000 lb./in.^{2} is reached, it is likely that the bow due to initial eccentricity will give an additional stress (due to bending) of 3,000 lb./in.^{2} in the skin: thus the total stress in the skin will be 30,000 lb./in.^{2}, the skin will buckle and induce premature flexural failure.

A simple method of allowing for these effects is to design for a theoretical failing load per inch P (assuming no eccentricity) somewhat greater than that actually required. A more refined method, which gives slightly more efficient structures, is to provide a slightly greater margin of flexural stress than is allowed for local buckling, the actual margin depending on the standard of straightness of the stringers which can be achieved.

It should be noted that even when initial eccentricity has been allowed for, the theoretical optimum design is also the practical optimum. However, in an actual design it is convenient to eliminate errors in the estimated failing stress (due to approximations in the present theory, to the use of clad skins, or to initial eccentricity) by one or two panel tests.

Although the present analysis was intended only as a guide to determining the best skin-stringer combination, in practice it has provided a quite reliable estimate of the strength of panels, agreeing closely with test results.

4. Z-SECTION STRINGERS—SECONDARY LOCAL BUCKLING CAUSING FAILURE[4]

4.1. General

In this class of design, the skin buckles at some stress below the failing stress of the panel. Strictly speaking the mode of buckling

involves movement of the stringer as well as the skin, and is in fact a complex one as mentioned in Section 3.1.

We now require to investigate the post-buckled behaviour, and so to arrange the geometry that the flexural instability stress is coincident with the critical stress for one or more secondary local buckling modes. These secondary local buckling modes may be of the nature of stringer local instability or stringer torsional instability, modified by restraint from the skin.

A rigorous solution to this problem is not yet in sight. Accordingly, approximate methods will be used; they are justifiable in the first place because, as has already been remarked, the weight of an optimum structure designed by such methods is very close to the true ideal minimum. A second justification appears at the end of the analysis; it is that the optimum structures determined here happen to be of such a type that the approximations used seem to be very close to the truth. We can make two general observations regarding efficient structures:—

(*a*) Coupling of modes reduces the lower instability stress and raises the higher, thus leading to an inefficient structure.

(*b*) The most efficient structure is that in which every type of instability which could cause failure occurs simultaneously.

By letting failure occur at more than about three times the skin buckling stress we achieve designs in which the stringers are relatively sturdy, and in which the coupling between skin buckling and stringer local distortion is negligible.

We now attempt to satisfy (*b*), namely that the local, torsional and flexural instability stresses shall be equal, and assuming that failure occurs at more than three times the skin buckling stress.

4.2. Instability stresses

Notation as in Section 3.1. It is assumed that $d/h=0.3$.

(*a*) *Skin buckling stress*

$$f_b=f_b/f_o\times 3.62E_T\,(t/b)^2 \quad . \quad . \quad (12)$$

(*b*) *Stringer local instability stress*

The following approximation is used for the edge stress at which stringer local instability occurs

$$f_L=3.62E_T\,(t_s/h)^2 \quad . \quad . \quad . \quad (13)$$

(*c*) *Stringer torsional instability stress*

The simple analysis developed by H. L. Cox[5] gives for the edge stress at which stringer torsional instability occurs

$$f_T=\frac{GJ-2\sqrt{E_THK}}{J'} \quad . \quad (14)$$

where

Stringer polar moment of inertia J' $=0.633h^3t_s$

Stringer St. Venant torsion constant J $=0.533ht_s^3$

Bending torsional constant H $=0.2h^2d^3t_s$

Skin support stiffness $K=Et^3/b$

Shear modulus G $=0.385E$

It should be noted that at edge stresses greater than about three times the skin buckling stress, the stringer rotation in the torsional instability mode is in the same direction for all stringers, owing to the effect of the skin buckles. We also note that the potential energy of the skin and lateral distortion of the stringer have been neglected; these are valid approximations in the present case.

(*d*) *Flexural instability stress*

We assume that after the skin buckles it has a constant

$$\frac{df_{\text{AVERAGE}}}{df_{\text{EDGE}}} \text{ of } 0.3.$$

For a stringer and a pitch of skin the tangent second moment of area is then

$$I_{NA}=\frac{0.19bt+0.47ht_s}{0.3bt+1.6ht_s}h^3t_s. \quad . \quad (15)$$

The load per inch at flexural instability is then

$$P=\frac{\pi^2E_T}{bL^2}\left(\frac{0.19bt+0.47ht_s}{0.3bt+1.6ht_s}\right)h^3t_s \quad (16)$$

(*e*) *Actual load per inch*

The expression for the load carried is

$$bP=f_{\text{EDGE}}\left(1.6ht_s+bt\left(0.3+0.7\frac{f_b}{f_{\text{EDGE}}}\right)\right) \quad (17)$$

4.3. Optimum designs

Using equations (12) - (17) we impose the condition that flexural, torsional and local buckling should occur at the same edge stress. Owing to the form of equation (14) it is not possible in this case to evolve a simple solution of the form

$$f\sqrt{\frac{L}{PE_T}}=constant,$$

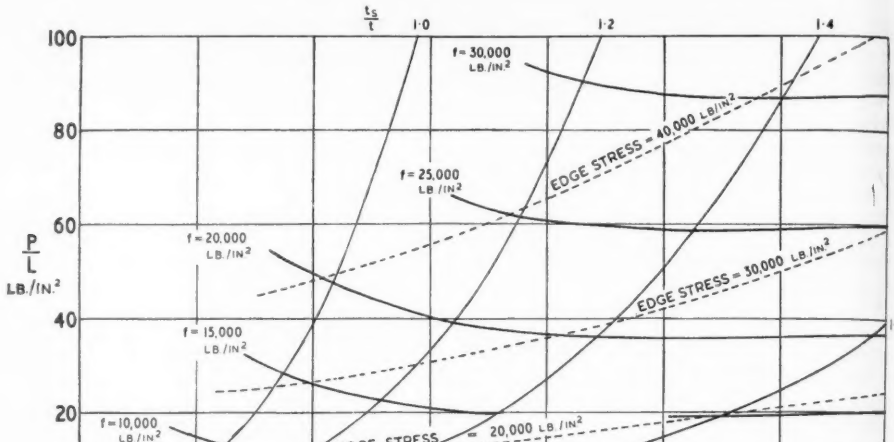


Fig. 4.
Design chart for optimum Z-section stringers where secondary buckling causes failure.
(Light alloy material.)

as for the unbuckled structure. Instead, the equations lead to families of solutions which are shown in Fig. 4 for light alloy ($E_T = 10^7$). It is notable that the realised mean stress f again depends on the structure loading coefficient P/L, and the mean stress realised by the optimum structure varies very nearly as $\sqrt{(P/L)}$ as in the case of the unbuckled designs. If we adopt this as a standard of comparison we see that the value of $F\left(=f\sqrt{\frac{L}{PE_T}}\right)$ realised is about 1.20, which is greater than for unbuckled designs; in fact as far as failure by elastic instability is concerned the buckled structure is superior to the unbuckled one. The limitation on the buckled structure occurs when the edge stress begins to exceed that permitted by present materials, which it does for values of P/L exceeding about 100 lb./in.². For values of P/L above this, the unbuckled type of structure will tend to become more efficient.

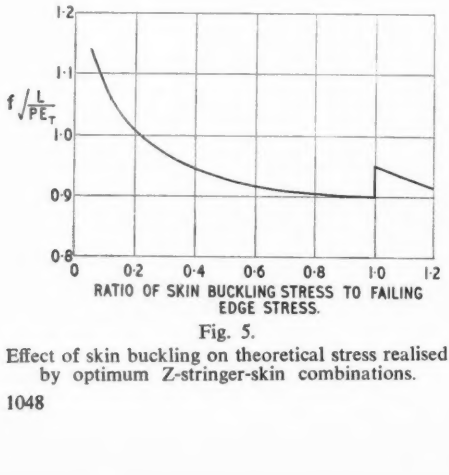


Fig. 5.
Effect of skin buckling on theoretical stress realised by optimum Z-stringer-skin combinations.

4.4. Relative merit of buckling and non-buckling designs

In Fig. 5 the structural efficiency, as measured by $f\sqrt{\frac{L}{PE_T}}$, of the designs is plotted against the ratio of the skin buckling stress to the edge stress at failure. It is seen that the skin should either not be allowed to buckle at all, or should buckle at a comparatively low stress, if good structural efficiency is desired.

In Fig. 6 the best possible results using Z-section stringers are given for current light alloy material. It is assumed that the optimum design is used, and the mean stress thus achieved is plotted against the value of

P/L. It is seen that the working stress, and hence the structural weight, is dictated entirely by the value of P/L which is used, and typical values of this quantity for various aircraft components are shown.

In practice, requirements of torsional stiffness may often cause the unbuckled design to be used. If a certain minimum skin thickness is required for stiffness, reference to Figs. 3 and 4 gives at once the stress realised by the best unbuckled design and the best buckled one, from which the choice of the better type of structure can be made for the particular case concerned.

5. OTHER TYPES OF STRINGER

5.1. Basis of comparison

We have now established that the structural efficiency of a skin-stringer combination can be measured by the constant F, which is $f\sqrt{\frac{L}{PE_T}}$ and which has a definite maximum value for any given type of stringer. The results of some similar calculations and tests for stringer sections other than Z are given below.

Type	*Theoretical best value of* $f\sqrt{\frac{L}{PE_T}}$	*Realised value*
Z-section, primary buckling causing failure	0.95	0.88
Z-section, secondary buckling causing failure ...	1.20	1.14
Hat section, primary buckling causing failure	0.96	0.89
Y-section, primary buckling causing failure	1.25	1.15

5.2. Structural efficiency of various types of stringer (optimum designs)

We see that of the range explored, the Y-section stringer is the most efficient, although for values of P/L less than 100 the buckled skin and Z-section is as good and in practice is more robust. Design charts similar to Fig. 3 can easily be plotted for each shape of stringer.

6. CHOICE OF MATERIALS

6.1. Extension of the theory

Consider a structure having a bay length L and sustaining a compressive load per inch width P. We have demonstrated that

$$f = F\sqrt{\frac{PE_T}{L}}$$

where F is a constant for the optimum design. The skin-stringer combination is therefore equivalent in weight to a skin of thickness T where

$$T = P/f = \frac{1}{F}\sqrt{\frac{PL}{E_T}} \quad . \quad (18)$$

If the density of the material is ρ, then the weight per unit area of skin-stringer surface is

$$W = \frac{\rho}{F}\sqrt{\frac{PL}{E_T}} \quad . \quad . \quad (19)$$

We see therefore that W is a minimum when the value of $\sqrt{E_T}/\rho$ is a maximum. (It is noteworthy that an analysis of tubular struts[6] by Pugsley also yields this result.)

On this basis Fig. 7 has been prepared to show the relative efficiency of optimum compression skin-stringer combination in various current materials. (It should be noted that for a given P and L the geometry of the structure will be different for each material, being adjusted to retain the optimum design for that particular material. It is assumed that such optimum designs realise $F = 1.15$.)

6.2. Comparison of materials

The results show that present aluminium alloys are the most efficient at high values of the loading coefficient P/L; at lower values of P/L, magnesium alloys are more efficient; at lower values still, wood is efficient, and for very low values of P/L (appropriate to model aeroplanes) balsa wood is indicated as the best structural material.

The potentially most efficient material is that with the largest value of $\sqrt{E}/\rho$ and

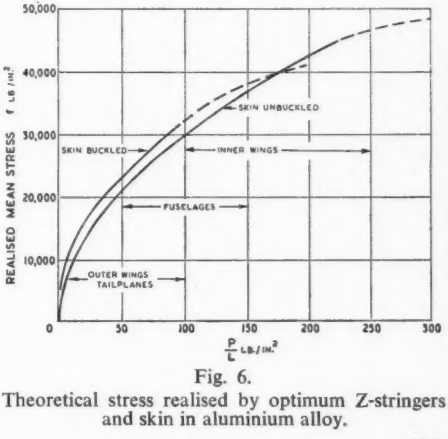


Fig. 6.
Theoretical stress realised by optimum Z-stringers and skin in aluminium alloy.

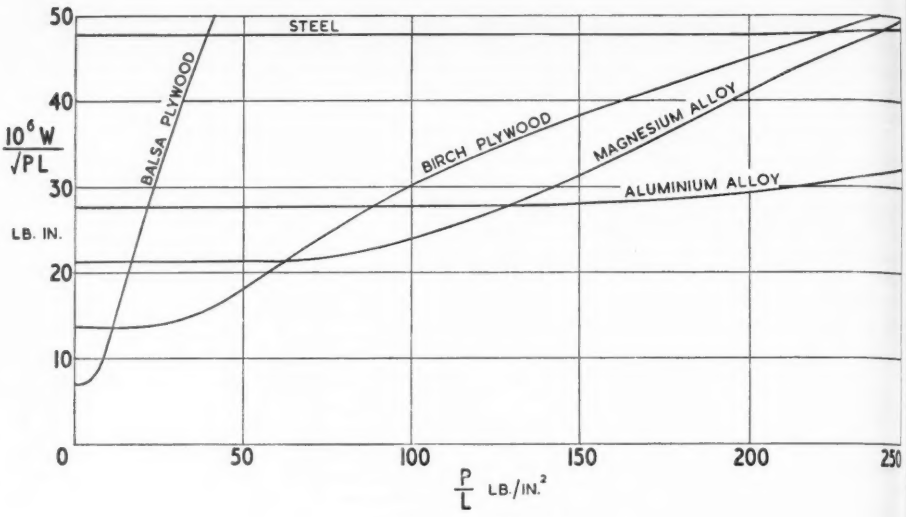


Fig. 7.
Relative weight of optimum skin-stringer combination in current materials.

magnesium alloys promise very well in this respect, since a 100 per cent. increase in proof stress would make them more efficient in general application than any increased strength aluminium alloy. A further promising development is an aluminium alloy with its Young's modulus increased by 30 per cent.: comparison with best present results is made in Fig. 8, where the effect of increased alloy strength is also shown.

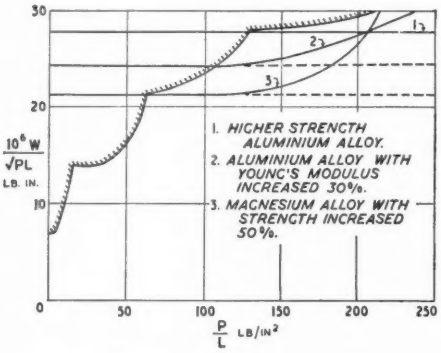


Fig. 8.
Relative weight of optimum skin-stringer combination in possible future materials.

7. CONSIDERATIONS AFFECTING RIB SPACING[7]

7.1. Object of analysis

Since the stress achieved by the skin-stringer combination varies as $\sqrt{(P/L)}$, a light combination for a wing is achieved by placing the ribs close together. When this is done, however, the weight of ribs may be considerable, and the structure of minimum weight in fact may be associated with a wider rib spacing, the increase of weight of the skin and stringers being more than offset by the saving on ribs.

Theoretical investigation of this problem is made difficult by the complex nature of the loads on a rib, and consequent ignorance of rib weights.

7.2. Determination of rib weight

The design of rib is a detail matter and the weight of a rib cannot be predicted in practice from pure theoretical considerations. Accordingly a more or less empirical approach must be adopted.

It can be demonstrated that in order to carry air load the strength of the rib must be directly proportional to the rib spacing, whereas to prevent general instability the stiffness of the rib must be inversely

proportional to the rib spacing. Since some parts of the rib will be designed by one consideration, some by the other, and some by minimum practical sizes, it appears likely that the weight per rib will not vary very greatly with the rib spacing.

Figure 9 has been prepared on this basis for some weighed bracing ribs in wings, tailplanes and fins on various aircraft. The low scatter of the values indicates that the ignoring of the effect of rib spacing does not introduce any serious error. In default of better information we will then assume that the weight of a rib does not depend on the rib spacing within practical limits.

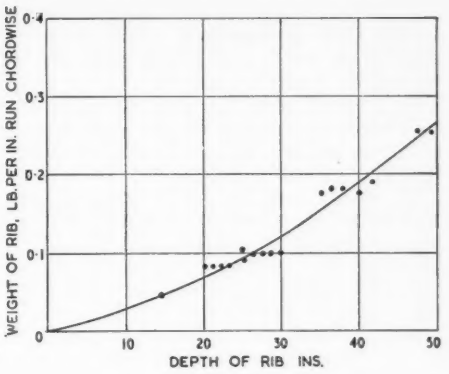


Fig. 9.
Typical weights of bracing ribs.

7.3. Determination of best rib spacing

Consider unit width of compression structure carrying a load per inch P at a mean stress f. The ribs are a distance L apart, while each rib has a depth D and is equivalent in weight to a plate of thickness T_R. We will assume for the present that all stresses are within the elastic range.

Then

$$f=F\sqrt{\frac{PE}{L}}$$

and the equivalent thickness T of the skin-stringer combination is

$$T=P/f=\frac{1}{F}\sqrt{\frac{E}{PL}}$$

When we include the weight of ribs, the total equivalent thickness becomes

$$\left(T+\frac{DT_R}{L}\right)$$

Now

$$T+\frac{DT_R}{L}=\frac{1}{F}\sqrt{\frac{PL}{E}}+\frac{DT_R}{L}$$

For the structure of minimum weight L must be chosen so as to make this quantity a minimum. Differentiating with respect to L and equating to zero we get (assuming F and E constant)

$$\frac{1}{2F}\sqrt{\frac{P}{EL}}-\frac{DT_R}{L^2}=0 \quad . \quad (20)$$

and

$$L=\left(\frac{4F^2D^2T_R^2E}{P}\right)^{\frac{1}{3}} \quad . \quad . \quad (21)$$

This is the optimum rib spacing, and we find that

Weight of skin and stringers per unit surface area $=\frac{2}{3}\rho\left(\frac{DT_RP}{E}\right)^{\frac{1}{3}}\left[\left(\frac{1}{4F^2}\right)^{\frac{1}{3}}+\left(\frac{2}{F^2}\right)^{\frac{1}{3}}\right]$

Weight of ribs per unit skin surface area

$$=\tfrac{1}{3}\rho\left(\frac{DT_RP}{E}\right)^{\frac{1}{3}}\left[\left(\frac{1}{4F^2}\right)^{\frac{1}{3}}+\left(\frac{2}{F^2}\right)^{\frac{1}{3}}\right]$$

7.4. Practical application

The foregoing analysis shows that the weight of ribs should be equal to about half the weight of the surfaces designed by compression. The analysis assumes that

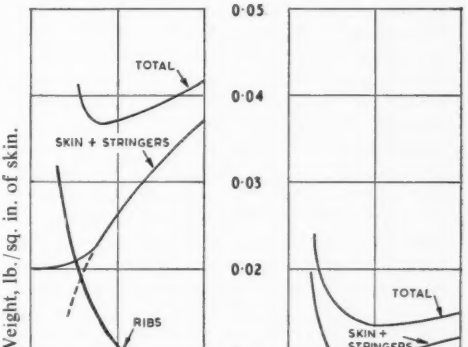


Fig. 10.
Examples of the variation of total weight with rib spacing.

P = 10,000 lb./in.	P = 2,500 lb./in.
Z-stringers.	Z-stringers.
Alum. Alloy.	Alum. Alloy.
Ribs 60 in. deep.	Ribs 25 in. deep.

secondary stringer stresses due to lateral loading are unimportant: this must be checked in each case but is generally an acceptable approximation.

It is also noteworthy that the depth and equivalent thickness of the ribs have as much influence on the configuration and weight of the structure as the load per inch itself.

In many cases, owing to practical considerations, the quantities F and E will vary somewhat with rib spacing; in such cases the nature of their variation always causes the optimum weight of ribs to be slightly less than half that of the skin and stringers. A satisfactory and rapid approach is to consider a range of values of L and find the total weight for each value; this has been done in Fig. 10 for a typical wing structure and for a large tailplane as examples.

By the nature of an optimum it is permissible to use a frame spacing slightly different from the optimum one without much weight penalty. It is advisable in practice to use a spacing slightly greater than that for pure minimum weight, since a simpler and more robust structure results.

8. CONCLUSIONS

No analysis of this subject can claim to be comprehensive, and the present one is no exception. Simplifications of the problem have been made, with the object of producing a fairly quick approximation to the optimum skin-stringer-rib combination; this simplification is essential because of the large number of variables involved. One must expect more detailed methods and a certain amount of testing to be used when checking the overall strength and stiffness once a structure has been fixed. It is of interest to note that the divergences in strengths from those found by the present simplified theory have been found, so far, to be quite small.

The importance of the structure loading coefficient P/L has been demonstrated, and design charts of the type derived here (based on P/L) permit a good approximation to the final optimum structure to be quite rapidly obtained, while continuous allowance is made for other practical design factors.

ACKNOWLEDGMENTS

The author's thanks are due to the Bristol Aeroplane Co. Ltd. for permission to publish this article. Research and test work done by the Bristol Aeroplane Company have provided much information on which some of the diagrams have been based, but the opinions expressed are those of the author.

Part of the analysis has been developed and published by workers in America, at the same time as it was developed independently in this country.

REFERENCES

1. ZAHORSKI, ADAM. Effects of Material Distributions on Strength of Panels. JOURNAL of Aeronautical Sciences, July 1944.
2. FARRAR, D. J. The Failing Stress of Flat Panels with Z-Section Stringers. The Bristol Aeroplane Co. Ltd., Technical Office Report No. 23, Sept. 1945. Scientific and Technical Memorandum No. 19/47.
3. ARGYRIS, J. H. The Initial Instability Stress of Flat Panels with Z-Section Stringers. R.Ae.S. Structures Data Sheet 02.01.25.
4. FARRAR, D. J. 1st Addendum, On the Design of Skin-Stringer-Rib Combinations for Compression Surfaces. Addendum to The Bristol Aeroplane Co. Ltd. Technical Office Report No. 39, August 1947.
5. COX, H. L. Instability of Stringers and Sheet-Stringer Combinations. A.R.C. Report No. Struct. 773.
6. PUGSLEY, A. G. The Relative Strength and Stiffness Properties Required for Struct Materials. A.R.C. Report No. Struct. 1113.
7. FARRAR, D. J. On the Design of Skin-Stringer-Rib Combinations for Compression Surfaces. The Bristol Aeroplane Co. Ltd. Technical Office Report No. 39, April 1947.

NOTES ON THE OPENING BEHAVIOUR AND THE OPENING FORCES OF PARACHUTES

by

F. O'HARA, M.A.

SUMMARY

AN approximate theory of parachute opening is suggested. A formula is derived for the critical opening speed (the highest speed at which the canopy develops fully) which indicates variation of the critical speed with fabric porosity, rigging line length and so forth, of the order observed in wind tunnel tests. Assuming a simple form for the air flow about the parachute, a formula is obtained also for the rate of opening of a canopy. This enables an analysis to be made of the motion of a store-parachute system during canopy development. The theory confirms the possibility of a large increase with altitude, found experimentally, in the maximum parachute force on the store.

1. INTRODUCTION

In the normal deployment of a parachute, the canopy is drawn away from the store (*i.e.* the dropped body) either by a static line fixed to the aircraft, or by a small spring-loaded auxiliary parachute. In consequence a considerable snatch force may occur in the parachute system when the rigging lines are fully deployed, because of the velocity of separation of the canopy-mass relative to the store[1]. Thereafter the canopy is fully unfurled or deployed and starts to open out.

The motion in the parachute system during deployment is fairly straightforward from the point of view of theoretical analysis, but the opening of the canopy is a more complex process and it has not yet been fully analysed.

Paper received October 1948.

Mr. O'Hara is Principal Scientific Officer, Airborne Forces Experimental Establishment.

Some light was cast on this problem in a paper by Duncan[2] and more recently by Scheubel [3] and much experimental work has been done to study the conditions required for satisfactory development of the canopy, and to investigate the factors affecting the opening[4, 5, 6, 7].

Reliable development is necessary for safety, but some control of the rate of opening through the parachute design characteristics is also desirable, because the forces in the parachute system during canopy development (which can be very large) depend on the rate at which the canopy opens. In the present paper some of the ideas in Refs. 2 and 3 are used in the derivation of an approximate theory, assuming a simple form of parachute and some knowledge of the air flow and pressure distribution, which is suggested for the process of parachute development. The theory is used to study the conditions required for opening and to analyse the motion of a store-parachute system during canopy development.

A list of symbols used is given at the end of the paper.

2. THE OPENING PROCESS OF A PARACHUTE

In the early stages of parachute development, the shape of the canopy is varied and uncertain, depending on the way it unfurls after release from the pack. As it inflates it takes a more definite form, similar to that of a collapsed or squidded parachute, and it appears from photographs that the opening of a parachute consists of a succession of shapes of this type.

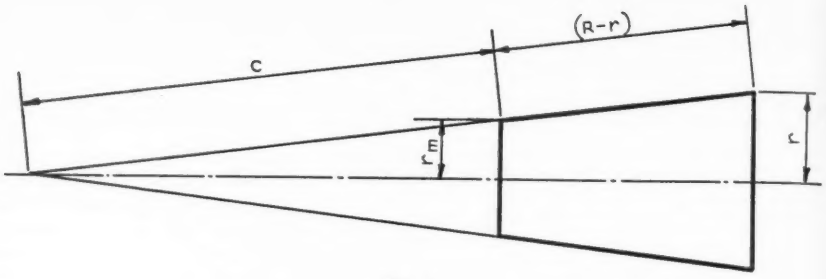


Fig. 1.
Parachute shape assumed for analysis of critical opening speed.

The typical features of a squidded parachute (good examples are shown in Fig. 2 of Ref. 2 and Fig. 11 of Ref. 4) include an inflated region near the crown of the canopy, with the remainder of the canopy fabric and rigging lines running in practically a straight line from the maximum radius to the point of attachment. This suggests that for approximate analysis of parachute opening, the parachute shape can be represented as having a flat head and straight sides converging with the rigging lines to the attachment point (Fig. 1). There is, however, considerable excess fabric at the mouth of the partially open canopy and with a finite number of rigging lines the mouth area may be reduced by indentations of the fabric. For simplicity, the case of an infinite number of lines, for which the excess fabric is distributed round the circumference without loss of area, is considered first and the effect of the number of rigging lines is discussed separately at a later stage.

Inflation of the canopy is evidently due to the inflow through the mouth exceeding the outflow through the porous holes of the canopy fabric. If v is the mean velocity of inflow, and r_m the radius of the mouth, then the total inflow is $\pi r_m^2 v$. Because the flow through porous fabric depends on the pressure difference across the fabric, most of the outflow from an actual canopy occurs at the region at the end of the canopy. It is assumed, for the simplified shape, that all outflow is through the flat end, so that if u is the mean velocity of outflow and r the radius of the end, the total outflow is $\pi r^2 u$. Hence if C is the volume of the canopy, then the opening equation of the parachute is

$$\frac{dC}{dt} = \pi r_m^2 v - \pi r^2 u \quad . \quad . \quad (1)$$

This is in the nature of an extension of the equation given by Scheubel[3].

If the canopy consists of fabric of length R from hem to apex, then when the end radius is r, the side is of length $(R-r)$. If the rigging lines are of length c, the radius of the mouth is given by

$$r_m = rc/(c+R-r) \quad . \quad . \quad (2)$$

In addition

$$C = \tfrac{1}{3}\pi \{ (c+R-r) r^2 - c r_m^2 \}$$

approximately, so that the opening equation becomes

$$\left\{ \frac{(c+R-r)^3 (2c+2R-3r) - 2c^3 (c+R)}{3r (c+R-r)^3} \right\} \frac{dr}{dt} = \left(\frac{c}{c+R-r} \right)^2 v - u \quad (3)$$

Analysis of the opening process therefore depends on knowledge of v and u. No general solution for the flow round and through a parachute canopy is yet available, but some information on the opening behaviour can be obtained from consideration of the parachute state in the neighbourhood of the critical opening speed, for which special conditions hold. This is dealt with in the next section. It is shown later (Section 2.2) that a simple formula can be obtained for the rate of canopy development by assuming a suitable form for the flow variation. This formula is used for analysis of parachute opening forces.

2.1. The critical opening speed

For speeds above the critical opening speed a parachute opens only to the squid state and it does not open fully unless the speed is reduced. Further, if the parachute is

open and the speed increased, the parachute may collapse to the squid state at a speed greater than the critical speed[5].

For a parachute in a steady squid state, the inflow to the canopy equals the outflow (the rate of opening being zero), and thus, from (1) and (2)

$$v=\left(\frac{c+R-r}{c}\right)^2 u$$

In the stationary state, there is equilibrium of forces across the mouth of the canopy. For an elongated form of the squidded parachute, in which the lateral force components are assumed negligibly small, the pressures on the inside and outside of the canopy mouth are approximately equal. The inflow velocity is therefore equal to the velocity outside the mouth, and for the elongated squid shape, this is approximately the free stream velocity, V. Thus, in the squid state,

$$V=\left(\frac{c+R-r}{c}\right)^2 u$$

approximately.

The critical opening speed may be taken to be the highest speed at which the canopy develops fully, or preferably in this case, the lowest speed at which the canopy does not develop fully. It is then the least value V_c, of the speed satisfying, for a small value, r_c, of the canopy radius, the relationship

$$V_c=\left(\frac{c+R-r_c}{c}\right)^2 u \quad . \quad (4)$$

The velocity u depends on the porosity of the canopy fabric and the pressure difference across it. In Ref. 2, it is shown that for the type of fabric used for parachutes, the effective permeability increases with increasing pressure difference and that in fact

$$u=f_1(p)\sqrt{p}$$

where $f_1(p)$ increases with p.

For convenience in the present analysis this is taken in the form

$$u \propto p^j \quad . \quad . \quad . \quad (5)$$

where $j>0.5$.

Neglecting the contribution to the parachute force from the sides of the canopy, the mean pressure difference across the end of the parachute is given approximately by

$$p=C_D \cdot \tfrac{1}{2}\rho V^2 \quad . \quad . \quad . \quad (6)$$

where C_D is the coefficient of parachute drag based on the maximum cross section area.

The porosity of the fabric is defined by u/V, and from (5) and (6),

$$\frac{u}{V} \propto C_D{}^j \rho^j V^{2j-1} \quad . \quad . \quad (7)$$

If the standard porosity q refers to a pressure difference p_s and if

$$p_s=\tfrac{1}{2}\rho_o V_s{}^2$$

then as in (7),

$$q \propto \rho_o{}^j V_s{}^{2j-1}$$

and so

$$\frac{u}{V}=qC_D{}^j\sigma^j\left(\frac{V}{V_s}\right)^{2j-1} \quad . \quad (8)$$

Using this relation in (4), the critical opening speed is given as the lowest value of the speed satisfying

$$V_c=\frac{V_s}{q^{1/(2j-1)}(\sigma C_D)^{j/(2j-1)}}\left(\frac{c}{c+R-r_c}\right)^{2j/(2j-1)}$$

It is not possible in considering only the axial flow to determine r_c, which depends on the lateral pressures and the rigging line tension. For an elongated parachute shape, however, r_c is small compared to c and may be neglected with small error. The formula for the critical speed then becomes

$$V_c=\frac{V_s}{q^{1/(2j-1)}(\sigma C_D)^{j/(2j-1)}}\left(\frac{c}{c+R}\right)^{2j/(2j-1)} \quad (9)$$

This is effectively the lowest speed at which the canopy does not tend to open at all and is probably all that can be accurately deduced without considering axial forces as well. When r_c is small, however, the variation of the critical speed with different factors should be given with reasonable accuracy.

Values of j of 0.58 and 0.75 are quoted in Ref. 2 for tests in which the fabric specimens were subject to only slight tension. In a parachute, an increase in pressure is usually associated with an increase in tension and this is likely to cause further rise in the porosity. The larger value of $j=0.75$ is used therefore for an illustrative example, and from (9),

$$V_c=\left(\frac{V_s}{q^2(\sigma C_D)^{1.5}}\right)\left(\frac{c}{c+R}\right)^4$$

According to this formula the variation of V_c with the rigging line length is given by

$$V_c \propto \left(\frac{c}{c+R}\right)^4\left(\frac{1}{C_D{}^{1.5}}\right)$$

and with porosity by

$$V_c \propto \frac{1}{(q^2 C_D{}^{1.5})}$$

It is shown in Ref. 6 that the drag coefficient of a developed parachute varies

with the porosity according to the empirical law

$$C_D = C_D^{\circ}(1 - 2.25u/V)$$

where C_D° is the drag coefficient of a similar canopy of non-porous fabric. It is assumed here that a similar relation may be used with equation (8) to approximate to the drag coefficient of a squidded parachute.

The rates of increase in V_c, with rigging line length, and as the porosity decreases, shown by the above analysis, are in good agreement with the wind tunnel results in Ref. 6. The absolute values of V_c are very high compared with measured values, but it is now shown that V_c may be much less when the number of rigging lines is not infinite.

It was pointed out in Section 2 that the mouth area of the canopy may be affected by the presence of excess fabric which, at speeds above V_c, appears to form inward indentations. In most cases these do not have a regular form, but to obtain an indication of the effect on V_c, their area is expressed as a fraction of the area of a simple triangular indent.

The circumference of the entry shaped by the rigging lines is $2\pi r_m$. If the length of fabric at the mouth is $2\pi H$ say, then with n rigging lines there is a length $(2\pi H/n)$ of fabric between the two lines. If this forms a symmetrical triangular indent on a base of length $(2\pi r_m/n)$ as shown in Fig. 2, the area of the indent is

$$\pi^2 r_m (H^2 - r_m^2)^{\frac{1}{2}}/n^2$$

Assuming that the actual indents are k/π times this value, then the effective mouth area is

$$\pi r_m^2 [1 - (k/n)\{(H/r_m)^2 - 1\}^{\frac{1}{2}}]$$

It may be shown by the same analysis as before that the critical opening speed is now given by

$$V_c = \frac{V_S}{q^{1/(2j-1)}(\sigma C_D)^{j/(2j-1)}} \left(\frac{c}{c+R}\right)^{2/(2j-1)} \left[1 - \frac{k}{n}\sqrt{\left\{\left(\frac{H}{r_c}\right)^2\left(\frac{c+R}{c}\right)^2 - 1\right\}}\right]^{1/(2j-1)}$$

With $j = 0.75$, the variation of V_c with the number of rigging lines is given approximately by

$$V_c \propto \left[1 - \frac{k}{n}\sqrt{\left\{\left(\frac{H}{r_c}\right)^2\left(\frac{c+R}{c}\right)^2 - 1\right\}}\right]^2 \times \left(\frac{1}{C_D^{1.5}}\right) \quad . \quad . \quad (10)$$

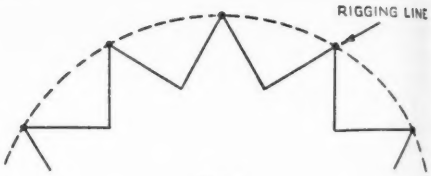


Fig. 2.

Part of section of canopy mouth showing simple triangular indents.

This formula shows that V_c decreases as the number of rigging lines is reduced. It is not easy to assess the effect in this case because of uncertainty about the shape of the indents, particularly at small r. The reduction of V_c obtained, however, assuming $c = 4R/3$, $r_c = H/4$, and $k = 1.2$, is from 1,500 f.p.s. with an infinite number of lines to about 100 f.p.s. with twelve lines.

The rapid opening of a canopy at a speed just below the critical value may be explained in terms of the excess fabric indents. For as V decreases through V_c, the inlet velocity becomes less than the stream velocity and the pressure inside the canopy mouth greater than outside, so that the excess fabric tends to bulge outwards. The mouth may therefore flick open with consequent rapid inflation of the canopy. The collapse of an inflated canopy at a speed higher than the critical opening speed may also be explained on similar lines.

Wind tunnel tests have shown that V_c also varies with hem cord length. Shortening the hem cord reduces the excess fabric at the mouth, so that the maximum possible indentations are reduced. From equation (10), however, reduction of the indentations leads to increase in V_c, whereas observation shows that V_c decreases as the hem cord length is decreased. A possible explanation is that shortening the cord has the effect also of stiffening the hem, so that fabric bulging inwards does not fold in so closely round the inner side of the mouth. The area of the indentations, in consequence, may increase as the hem cord is shortened, and V_c therefore decreases also. In terms of the above analysis, this means that as H is reduced, k increases, and if in the previous example H is reduced by 25 per cent., then with $k = 1.7$, V_c is decreased further to about 75 f.p.s.

Another factor affecting the critical speed is the size of the parachute. An explanation

of the increase of V_c as the parachute size is reduced is given by Young[7] in terms of the effective Reynolds number, although he notes that the observed increase is not so rapid as the inverse of the diameter as thus predicted. This may be due to the fact that as the size is reduced, the fabric is relatively stiffer and the mouth indentations tend to be greater. This has the effect of reducing the critical speed and may partially offset the increase due to the scale effect.

2.2. The Rate of Parachute Development

Some general deductions about the rate of parachute development are possible from analysis similar to that used for the critical opening speed. For example, from the form of the parachute opening equation (3), it may be seen that, in general, factors reducing the mouth inflow in proportion to the end outflow lead to slowing down of parachute development.

To determine the rate of opening of the canopy further simplification is necessary. If a canopy shape with parallel sides is taken (this means that the rigging lines are long compared to the canopy radius), the volume is $\pi r^2 (R-r)$ and the opening equation now becomes

$$\frac{d}{dt}\{\pi r^2 (R-r)\} = \pi r^2 (v-u) \qquad (11)$$

A general solution for the flow velocities is not available, but it appears that at the beginning of inflation, when r is approximately zero, $v=V$; and at the end, when the steady state is attained, $v=u$. Considering first the case of a canopy of non-porous fabric, for which $v=0$ finally, the simple assumption is made therefore that v decreases linearly from $r=0$ to a steady state at $r=r_s$, so that

$$v = V(1-r/r_s).$$

For a canopy of porous fabric, if $(1-h)$ is the fraction of the inflow going through the fabric at any stage, then

$$h = 1-u/v \qquad . \quad . \quad (12)$$

h is taken to be a parameter of the canopy, and the assumed form of variation of v is generalised, for a canopy of porous fabric, to

$$v-u = hV(1-r/r_s)$$

This relation, used with (11), leads to a formula for the rate of opening of the canopy. The form obtained is, however, much simplified if it is assumed, as in Ref. 3, that $r_s = 2R/3$. The flow relationship then becomes

$$v-u = hV(1-3r/2R)$$

and so, substituting in (11),

$$\frac{dr}{dt} = \frac{hVr}{2R} \qquad . \quad . \quad (13)$$

This formula determines the rate of opening at a given radius and speed, if the value of h is known. So far there is little experimental evidence to show whether the formula is accurate or not, and it is, in fact, apparent that the theory can only apply during the stage when the constraining effect of the rigging lines is unimportant. Rough estimates from the formula, however, compare reasonably well with opening rates deduced from ciné records of parachute drops.

The form obtained for the rate of opening is helpful mathematically in that, when used with a constant mean value for h, it leads (as shown in Section 3) to an integrable form of the equation of motion of a store and opening parachute. The main difficulty in the application of the formula is the estimation of the mean value to be taken for h. This parameter is a function of v and u and so, implicitly, of the speed, the canopy radius, and the force coefficient. Since it is necessary to know h to determine the variation of these quantities, a process of successive approximation is involved. Greater accuracy is possible in the analysis if the porosity of the canopy fabric is small and h nearly unity.

3. Parachute Development Forces

The system considered for analysis of the parachute opening forces consists of a store of mass, M, with a partially open parachute of radius, r. The air speed of the system is V. The air drag of the store is neglected and the ordinary air drag of the parachute is taken to be of the same form as in steady conditions, namely $L\rho r^2 V^2$, where $L(=C_D\pi/2)$ is a function of the canopy fabric porosity. It is assumed that there is a virtual air mass associated with the parachute, of the form $K\rho r^3$, K being constant. Then, neglecting the elasticity of the system, the equation of motion for approximately horizontal motion in which the effect of gravity is small, is

$$\frac{d}{dt}\{(M+K\rho r^3)V\} = -L\rho r^2 V^2$$

or

$$(M+K\rho r^3)\frac{dV}{dt} = -L\rho r^2 V^2 - 3K\rho r^2 V \frac{dr}{dt} \qquad (14)$$

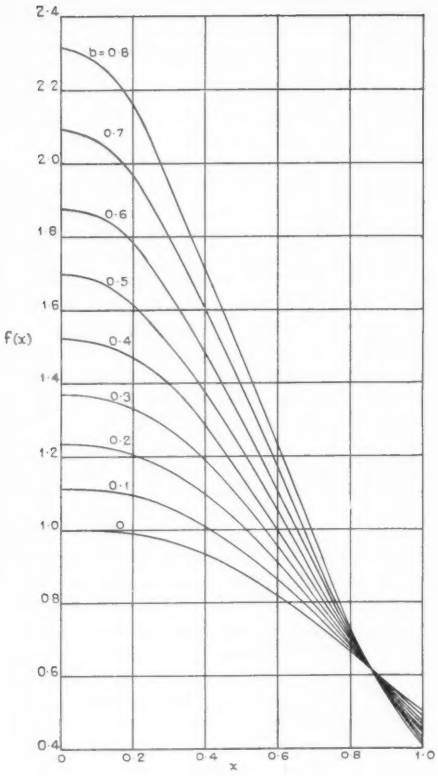


Fig. 3.

Chart of $f(x)=\left\{\dfrac{(1+x)^b\sqrt{3}}{(1+x^3)^{1+b/\sqrt{3}}}\right\}e^{2b \arctan\{(1-2x)/\sqrt{3}\}}$

With the relationship for (dr/dt) from (13), equation (14) may be reduced to an equation in V and r, with two varying parameters L and h. For the determination of L, it is assumed, as in Section 2.1, that the drag coefficient of the partially open canopy varies with porosity according to the empirical law

$$C_D = C_D^{\circ}\,(1-2.25u/V) \quad . \quad (15)$$

where C_D° is the drag coefficient of a similar canopy of non-porous fabric. The porosity ratio, u/V, depends on the pressure difference across the end of the canopy and varies with the force coefficient C_T, instead of the steady drag coefficient, C_D, as in (8). Thus

$$\frac{u}{V} = q\,(C_T\sigma)^j\left(\frac{V}{V_s}\right)^{2j-1} \quad . \quad (16)$$

The force coefficient is a function of r, V and (dV/dt), because

$$C_T = (\text{parachute force})/(\tfrac{1}{2}\rho\pi r^2V^2)$$

and

$$\text{parachute force} = -(M+K\rho r^3)\frac{dV}{dt} \ .$$

From equation (12) in Section 2.2, the opening parameter, h, may be written

$$h = 1-\frac{(u/V)}{(v/V)} \quad . \quad . \quad (17)$$

where (u/V) is as in (16), and

$$v/V = 1-3r/2R.$$

A numerical solution might be found to these equations of the opening motion by a step-by-step method, but the only solution considered here is that in which L and h are assumed constant. Since these quantities depend on r, V and dV/dt, successive approximation is necessary to determine suitable mean values to be used in the analysis of a particular problem. When L and h are constant, equations (13) and (14) may be combined to give an equation of the form

$$\left(\frac{1}{V}\right)\frac{dV}{dx} = -\sqrt{3}\,.\,(2bx+\sqrt{3}\,.\,x^2)/(1+x^3)$$

where

$$x = r/a$$
$$a = (M/K\rho)^{\frac{1}{3}}$$
$$b = RL/(\sqrt{3}\,.\,fKa).$$

Hence, if $V=V_o$ and $x=x_o$ initially, then

$$V = V_o\frac{f(x)}{f(x_o)} \quad . \quad . \quad (18)$$

where

$$f(x) = \left\{\frac{(1+x)^b\sqrt{3}}{(1+x^3)^{1+b/\sqrt{3}}}\right\}e^{2b \arctan\{(1-2x)/\sqrt{3}\}}$$

$f(x)$ is charted in Fig. 3 as a function of x and b.

From (13) and (18), the rate of opening of the canopy is

$$\frac{dr}{dt} = \left(\frac{hV_oax}{R}\right)\frac{f(x)}{f(x_o)} \quad . \quad (19)$$

The force on the store $(-MdV/dt)$, is, from (14), (18) and (19),

$$T = \frac{L\rho a^2x^2V_o^2\,(1+\sqrt{3}x/2b)}{(1+x^3)}\left\{\frac{f(x)}{f(x_o)}\right\}^2 \quad (20)$$

Equations (18), (19), (20) represent the solution for the motion of the system and the force on the store during the development of the canopy. Results from the theory appear to be in reasonable agreement with the

observed values in Ref. 1. In Section 3.1 the theory is used to compare the forces on a store at two different altitudes.

It is worth noting that a simple formula for the force maximum during parachute development is obtained when a constant mean value is used for the rate of opening of the canopy. It is shown with this assumption, in Ref. 1, that if T_D is the force maximum, and m the mean rate of opening,

$$T=(4Mm/9)^{\frac{1}{2}}\, V_o\,(L\rho V_o+3K\rho m)^{\frac{1}{2}}$$

the radius being

$$r_D=\{\,3Mm/[2\,(L\rho V_o+3K\rho m)]\,\}^{\frac{1}{2}}$$

Hence

$$T_D=(2MV_o m)/(3r_D)$$

and if t_D is the time from the beginning of development to the force maximum

$$T_D=(2MV_o)/(3t_D)$$

Values of T_D and t_D are given for one system at different altitudes in Ref. 8. Using the measured values of t_D, which decrease considerably with altitude, the estimated increases in the force maximum are in good agreement with the measured results.

3.1. The effect of altitude on parachute forces

The parachute forces on a 200 lb. store at sea level (relative air density $\sigma=1$) are compared in this section with the forces in the same system at 44,000 ft. ($\sigma=0.2$). The launching speed at both heights is 340 f.p.s. T.A.S.

The first point to consider in determining the forces is the air speed of the system when parachute deployment is complete and the canopy begins to open. At a given true air speed, the drag of the store and parachute packs, during deployment in low density conditions, is less than at sea level. The reduction in speed during deployment is therefore also less. A method of estimating the speed reduction is given in Ref. 8 and by extrapolation from the results in that paper it is estimated that the speeds at the end of deployment are approximately 270 f.p.s. at $\sigma=1.0$ and 310 f.p.s. at $\sigma=0.2$.

The air mass $K\rho r^3$, associated with the parachute, includes the mass inside the canopy and a virtual mass assumed to be similar in size to that for a flat disc of the same radius as the parachute. A reasonable estimate therefore is that the air is equivalent to that of a sphere of radius r, so that $K=4\pi/3$. The value of R, the distance from the hem to the apex of the canopy, is taken to be 15 ft.

The drag coefficient, C_D, varies with porosity as shown in (15) and (16). For a comparatively porous fabric ($q=0.2$), it is estimated, using the porosity variation index $j=0.75$, that the mean value of C_D during development is roughly 0.75 at $\sigma=1$, and 1.10 at $\sigma=0.2$.

The variation of porosity with density and speed also affects the rate of opening factor, h. On the basis of equation (17), the

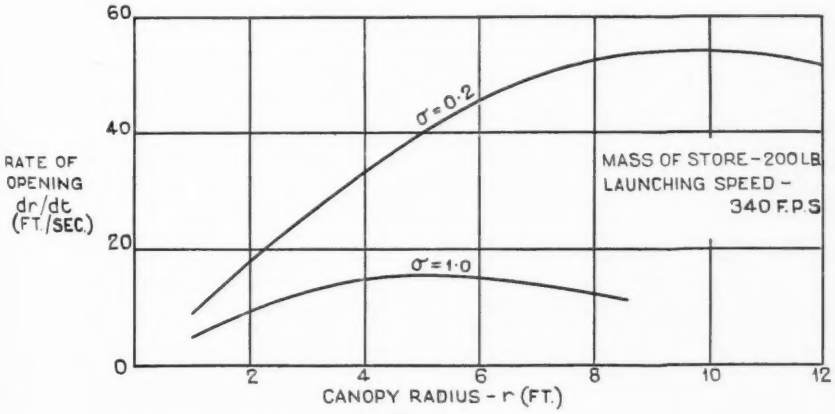


Fig. 4.
Comparison of parachute opening behaviour in two air density conditions.

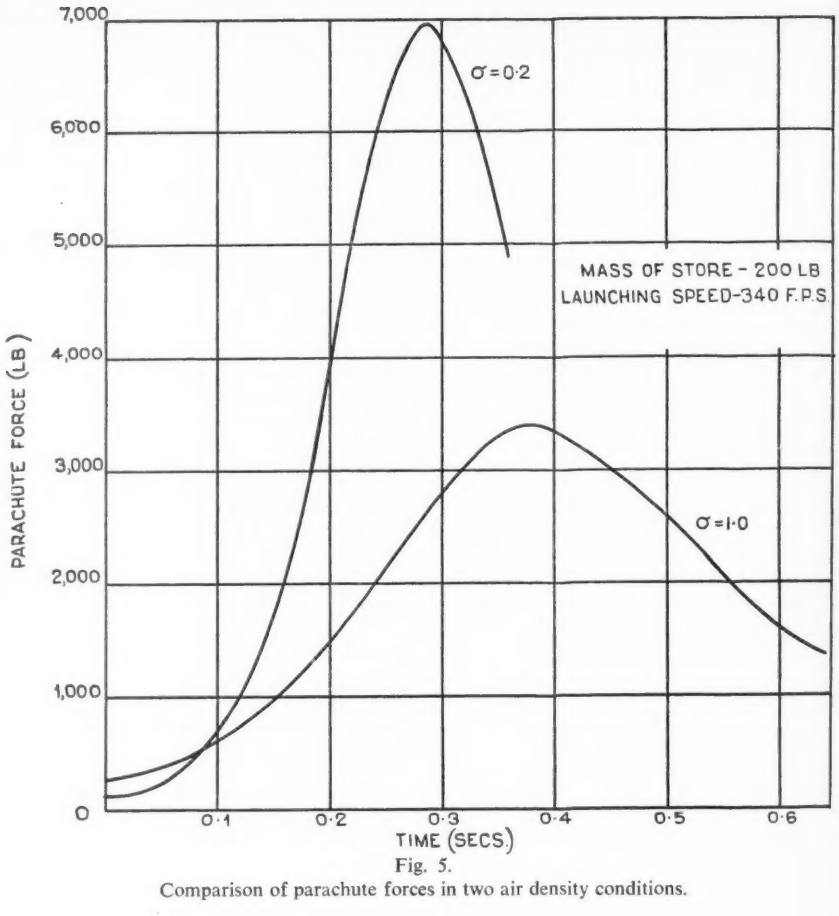


Fig. 5.
Comparison of parachute forces in two air density conditions.

approximate values taken for h are 0.55 at $\sigma=1$, and 0.85 at $\sigma=0.2$.

Estimates of the rate of opening of the canopy and of the force on the store have been made using these values of the constant in equations (19), (20) and Fig. 3. (dr/dt) is plotted against r in Fig. 4, and force against time in Fig. 5. The rate of opening at high altitude (up to 54 ft./sec.) is much greater than at sea level (up to 16 ft./sec.). The forces are also considerably greater, the maximum at $\sigma=0.2$ being $35W$ compared to $17W$ at sea level. This compares reasonably well with the increase noted in measured results (Ref. 8).

According to the above analysis, the increase in the maximum force with altitude is due to a combination of causes. In the first place, because of the lower drag of the system during deployment, the air speed at the start of canopy development is greater at high altitude. The ordinary air drag coefficient is also greater at lower porosity, but even so, because of the reduced air density, the parachute force increases with radius initially less quickly at the high altitude. The initial decrease of speed with radius is therefore smaller and since, in addition, the effective porosity is reduced, the rate of opening becomes correspondingly greater. At the later stage, when the maximum force develops, there is at high altitude a greater velocity, radius and rate of opening, than at low altitude. The ordinary

air drag is actually then greater than at the maximum at low altitude, but the main increase in the force maximum is due to a very much larger contribution from the rate of change of momentum of the growing virtual air mass associated with the parachute.

3.2. The constraining effect of the rigging lines

The accuracy of the theory probably decreases as r increases, because the constraining effect of the rigging lines is not included. The end stage of the canopy development is not, therefore, covered by the theory, and if the force maximum is found to occur at a large value of r, it may be necessary, for complete analysis, to assume simply that the rate of opening decreases linearly to zero during a suitable interval at the end of canopy inflation. Photographic measurements show that parachute development comes to a comparatively abrupt halt, usually at a radius greater than that in steady descent. Partial collapse therefore follows the peak inflation, but the force is then decreasing, because the speed is falling off as well as the radius.

An indication of the constraining effect of the rigging lines may be obtained from an equation of work. The work done in opening the canopy to radius r against the lateral component of tension is approximately

$$\int_0^r T\left(\frac{r}{c}\right) dr.$$

Hence if δs is an increment of longitudinal distance,

$$\left(-M\frac{dV}{dt}\right)\delta s = \left\{\frac{d\,(K\rho r^3 V)}{dt} + L\rho r^2 V^2\right\}\delta s + \\ + T\left(\frac{r}{c}\right)\delta r$$

and since

$$T = -\frac{M}{\sqrt{(1-r^2/c^2)}}\frac{dV}{dt}$$

then

$$\left[M\left\{1-\frac{r\,.\,dr/dt}{cV\sqrt{(1-r^2/c^2)}}\right\} + K\rho r^3\right]\frac{dV}{dt} \\ = -L\rho r^2 V^2 - 3K\rho r^2 V\,.\,\frac{dr}{dt}$$

This is of the same form as equation (14), with the mass M multiplied by a factor F, which, putting $dr/dt = \frac{1}{2}hVr/R$, becomes

$$F = 1 - hr^2/\{2Rc\,(1-r^2/c^2)^{\frac{1}{2}}\}$$

The effect of this factor is only appreciable at large values of r, and although a general solution for V is still possible when it is included, the extra complication is scarcely justified. If a mean value of F is used, it shows the constraint to have the same effect as reducing the mass of the store.

4. Acknowledgment

Acknowledgment is made to the Chief Scientist, Ministry of Supply for permission to publish this paper.

References

1. O'Hara, F., and Thompson, A. G. An Investigation of the Forces on Equipment During Parachute Development. Report No. A.F.E.E./Res. 15. April 1945.
2. Duncan, W. J. The Cause of the Spontaneous Opening and Closing of Parachutes. (The Phenomena of "Squidding"). R. & M. No. 2119. December 1943.
3. Scheubel, F. M. Notes on the Opening Shock of a Parachute. B.I.O.S. Interrogation Report No. 104. April 1946.
4. Brown, W. D., and Harrison, K. Design of Parachutes for Large Bombs. R.A.E. Report No. Arm. 177. (A.R.C. 5899). Nov. 1941.
5. Richards, G. J. Tests in the R.A.E. Large Wind Tunnel on the "Squidding" of Parachutes. R.A.E. Report No. Exe./125. June 1942.
6. Johns, T. F., and Auterson, E. I. The Effects of Various Factors on Parachute Characteristics. R.A.E. Technical Note No. Aero. 1365. (A.R.C. 7453). January 1944.
7. Young, A. D. Notes on the Aerodynamic Characteristics of Parachutes. R.A.E. Report No. Aero. 1752. (A.R.C. 5886). May 1942.
8. Howard, H. B. Loads and Opening Times of Parachutes. C.T.I. Tech. Note No. 155. October 1944.

NOTATION

$a = (M/K\rho)^{\frac{1}{3}}$.
$b = RL/(\sqrt{3}\,.\,hKa)$.
c = rigging line length.
C = volume of canopy.
C_D = parachute drag coefficient.
C_D° = drag coefficient of parachute with canopy of non-porous fabric.
C_T = coefficient of parachute force.
e = exponential number.
$F = 1 - \dfrac{hr^2}{2Rc\sqrt{(1-r^2/c^2)}}$
$h = 1 - u/v$.

H = (canopy hem length)/(2π).

j = index defining variation of u with p; $u \propto p^j$.

k = $\pi \times$ ratio of areas of actual canopy indent and triangular indent.

K = (air mass associated with parachute)/(ρr^3).

L = (parachute drag)/$(\rho r^2 V^2)$.

m = mean rate of parachute development.

M = mass of dropped store.

n = number of rigging lines.

p = mean pressure difference across the end of the parachute canopy.

p_S = pressure difference for standard porosity.

q = standard porosity.

r = maximum radius of canopy.

r_c = value of r at the critical opening speed.

r_D = value of r at the development force maximum.

r_m = canopy mouth radius.

r_s = canopy radius in steady developed condition.

R = distance from hem to apex of canopy.

s = longitudinal distance.

t = time.

t_D = time from beginning of development to the force maximum.

T = parachute force.

T_D = development force maximum.

u = mean outflow velocity through end of canopy.

v = mean inflow velocity through the mouth of canopy.

V = air speed.

V_c = critical opening speed.

V_o = initial air speed.

V_S = $(2p_s/\rho_o)^{\frac{1}{2}}$.

x = r/a.

ρ = air density.

ρ_o = air density in I.C.A.N. sea level conditions.

σ = relative air density, ρ/ρ_o.

AIRCRAFT DEFECT REPORT PROCEDURE

by

A. H. C. GREENWOOD, A.R.Ae.S.

THIS review is an attempt to examine, very briefly, the existing methods by which the airframe, engine and accessory manufacturers are informed of the operational troubles which are experienced by the users of their equipment, and how these manufacturers thus come to possess the knowledge which alone can enable them to avoid the recurrence of similar faults in the future. The importance of this knowledge can hardly be over-emphasised, but it is suggested that, in the past, there has been an abundance of such information which has failed to reach the right people at the right time.

For the purpose of this review it is proposed to divide the troubles to which the aeroplane is heir, into three main categories:—

1. Aerodynamic or handling faults.
2. Structural or design failures.
3. The general unreliability of components which causes low serviceability and utilisation rates.

The sources from which the manufacturer obtains information on these points, be they airframe, engine or accessory, fall into certain clearly defined divisions:—

The manufacturer's own prototype trials, and subsequent production testing. These can be expected to reveal the majority of the aerodynamic or handling troubles, although the comparatively short duration of these tests may preclude the observation of some quite serious faults, which are later shown up by unusual local or climatic conditions. In addition, it is often found that the performance of the production version varies appreciably from the results obtained during prototype trials. These variations are normally the subject of rapid correction because the manufacturer is immediately aware of such shortcomings and can act accordingly.

The official acceptance trials, by the Ministry of Supply or the Air Registration Board. These naturally provide an extremely valuable independent expert opinion on the product, and will undoubtedly indicate a further variety of shortcomings which were not apparent to the manufacturer. The scope of these trials is much greater than the prototype trials, held by the makers, with particular application to the effect of climatic extremes, but again, their length is usually insufficient to reveal many of the smaller defects which long service alone can make apparent.

The Service Defect Procedure of individual reports on Forms 1022 or A.21. This is, perhaps, the nearest existing approach to a comprehensive system for dealing with the many smaller defects, but the very magnitude of the task means that a vast amount of paper work must be dealt with, and this in turn results in varying degrees of duplication of effort and slow rectification action. Thus a feeling of frustration is engendered in the originators, and in time is reflected by a lower standard of accuracy in later reports.

The A.R.B. Civil report system. This has hardly been operating long enough to assess its efficacy, but it does seem that inevitably it will suffer from many of the limitations of the Service procedure, without providing the latter's wide scope. In addition, it would seem that there is a further disadvantage in the fact that each report emanates from one of the Board's surveyors, and not from the actual operator who has experienced the trouble.

Paper received 8th July, 1949.

Mr. Greenwood is a member of the Design Staff of Vickers-Armstrongs Ltd., Weybridge and an Engineer Officer, R.N.V.R.

The opinions expressed in this Note are his own and not necessarily those of his Company nor of the Service.

Reports from Operating Companies, and Owners of aircraft, or from the Manufacturer's representatives stationed with the Service or airlines. Perhaps these are the most valuable sources of information at present available to the manufacturer. By these means he is virtually in direct touch with each trouble, as it occurs, and if the information is sufficiently detailed, rapid remedial action can be initiated. This information is made more valuable by the fact that it is not limited by the bounds of any official form, neither is it inadvertently delayed nor distorted by any intermediary.

It will be seen therefore that the ambit of the existing procedure may well be expected to deal as adequately as possible with aerodynamic and structural problems, but that the present organisation for dealing with the causes of petty unserviceability leaves much to be desired. This is amply confirmed by the experience of those who have recently been using, in civil aircraft, equipment developed during the war years for the Royal Navy or the Royal Air Force. It is a frequent experience for a civil operator's defect report, on such an item of equipment, to evoke the manufacturer's comment that no previous complaints have been received during several years of Service use, although the fault is quite obviously inherent in the basic design.

Many man-hours and large sums of money daily can be, and indeed are, expended in tracing and rectifying these comparatively minor but recurrent troubles. There is a strong case, both economically and technically, for examining and revising the existing procedure for reporting minor and recurrent service troubles.

It is suggested that a review might be made with the following objects in mind:

1. To increase the flexibility of the existing systems by introducing a more direct form of contact between user and maker.
2. To ensure that the user is kept fully informed of the course of action which has resulted from his report, even if it eventually becomes abortive, in which case an explanation should be forthcoming as to the reasons for the failure to bring about an improvement.
3. To foster a spirit of greater urgency throughout the many intermediaries who handle each report on its journey from the originator to the manufacturer.
4. To expedite the promulgation of the remedial action resulting from defect reports, with particular reference to the Service user.

There are undoubtedly many additional points of existing procedure which could be improved, but it is believed that the achievement of the four main aims listed above would bring about a marked increase in the daily utilisation rates of both Service and civil aircraft.

(*Correspondence will be welcomed on this* subject.—ED.)

REVIEWS

GLOSSARY OF AERONAUTICAL TERMS. BRITISH STANDARD 185. PART 2. 1949. British Standards Institution, London. 3s. net.

To anyone accustomed to the consistently high standard of the majority of B.S.I. publications, this latest issue of Part Two of a revised edition of the Glossary must come as a shock and a disappointment. While the Foreword states that Part Two has been issued in advance of the others in order to cover the new field of gas turbines, it is felt that such haste is no excuse for the lack of balance in its composition, the numerous and serious omissions, and, too frequently, the poor syntax and poorer definitions.

Part Two includes sections on the Power Plant (*sic*), covering sub-sections on general items, piston engines, and gas turbines and jet propulsion; on propellers; and on auxiliary services, hydraulic, pneumatic, and electric.

A glossary of this kind must surely be of all things complete, accurate, free from ambiguity, and easily understandable by the foreigner. Unfortunately, particularly in the section on piston engines, it is none of these things. Right at the outset there is no definition of the term Power Plant, which has a different meaning in this country from that in the U.S., for example. There are definitions of seven types of oil cooler, twelve types of coolant radiator and confused and lengthy descriptions of forked and articulated and side-by-side and slipper-type connecting rod assemblies. Yet there is no mention of poppet valve and sleeve valve engines, exhaust valves. valve seat inserts, cams, rockers, cylinder heads, barrels, blocks and liners, rocker compensating gear, crankshaft main bearings, and so on, although the crankcase (not oil) sump gets a mention.

Only an older generation of aircraft engineers would clearly understand from the definition that the cylinders of a rotary engine revolved around the crankshaft and not about their own axes.

Compared with much more of this kind of thing, the section on gas turbines provides a refreshing change. Obvious omissions, however, are the turbine blade and its fir tree root fixing, compressor surge, and heat exchangers. The compressor drum is allowed to embrace the disc type, which is not strictly accurate. One purpose of the Glossary is to set a standard for terms, but when rotating guide vanes are already widely known as r.g.v's. it is surely too late to try and insist upon " impeller intake guide vanes."

The propeller section shows a bias towards the theoretical side, but is otherwise good. Omitted are paddle blades and blade root cuffs, slinger rings and constant speed units.

The British Aircraft Industry deserves a better Standard Glossary than this.

Comments from Lt.-Col. W. Lockwood Marsh

As a member since 1920, and Chairman since 1930, of the Aeronautical Glossary Committee of the British Standards Institution, I wish to make the following comments on your reviewer's strictures on the Power Plant Section of the new edition.

In the first place, the Committee consists of representatives nominated by, among other interested bodies, the Ministry of Supply (several departments), the Air Ministry, the Patent Office, the S.B.A.C. (one of whose nominees was a delegate from one of the principal aero-engine firms) and the Royal Aeronautical Society—neither of whose representatives was, however, present at any of the meetings at which the power plant terms were discussed. In addition, a nominated representative of the Directorate of Engine Research and Development attended by invitation all the meetings at which the terms included in this Section were

considered. The individuals responsible were, therefore, fully representative of all the interests concerned. Furthermore, the draft as approved by the Committee was, in accordance with B.S.I. practice, circulated externally for comment and the various suggestions received (particularly from three aero-engine firms other than the one specifically represented at the meetings) were considered, and most of them accepted and incorporated. In every single instance agreement on the decision to include, or reject, a term and the precise wording of its definition was unanimous. The consensus of opinion in favour of the Section as it stands is, therefore, impressive.

I should like to emphasise that it is a *British* standard and consequently the question of the use of words with a different meaning in other countries does not arise—nor, I suggest, need it be "easily understandable by the foreigner."

The "confused and lengthy descriptions" of the various types of connecting rod assembly originally appeared in the 1923 edition and have been reconsidered and adopted without alteration for the 1930, 1940 and present editions. As the personnel of the Committee was on each occasion entirely reconstituted with fresh nominees the consensus of opinion is, again, impressive. The same applies to the definition of a rotary engine.

With regard to "impeller-intake guide-vanes" and "rotating guide-vanes," your reviewer refrains from mentioning that the latter (which he happens to prefer) is shown as an alternative to the former (which the Committee considers preferable) and that both are given, in each instance under two headings, in the Index.

Your reviewer criticises certain omissions, but the terms he lists are familiar to any owner of a motor-car. The glossary is, and has always been since its inception by the Royal Aeronautical Society in 1910, advisedly confined as far as possible to terms of purely aeronautical significance. Otherwise it would become a dictionary of general engineering; in which case the constitution of the committee would have to be quite different and the whole scope of its discussions widened out of all recognition.—W. LOCKWOOD MARSH.

THE FUNDAMENTALS OF GAS TURBINE TECHNOLOGY. W. R. Thomson. Power Jets (Research and Development) Ltd., London. 1949. 148 pp., 117 Diagrams. 26s. net.

Although certainly dealing with fundamental theory, this book is obviously intended for those with a fair knowledge of engineering science. No space is wasted on lengthy explanations and the style is such as to demand an alert mind on the part of the reader if full value is to be extracted from the subject matter.

In writing a book of this nature, the author is faced with a difficult task in the selection of material, but nevertheless, a criticism that can be levelled at the present book is that it deals only with the thermo-dynamic side of the subject and excludes the equally important basic aerodynamic approach. Within this limitation, the layout of the book is good and the subject matter is presented in a clear and logical fashion.

The early part of the book deals with basic thermodynamics and the application to gas turbine cycles. In the former, the treatment is concise, and particularly welcome is the clear exposition of the concept of polytropic compression and expansion and the thermodynamics of continuous flow processes. Naturally, entropy charts and their usefulness receive prominence, but the author here has concentrated on temperature-entropy diagrams to the exclusion of the very useful total heat-entropy method of plotting. Types of gas turbine cycles are dealt with exhaustively, but more cycle performance curves would have been welcome. The reader, no doubt, will find instructive the description given at the end of this section, of cycles now in actual use, and will appreciate the data given on the properties of air and of fuel-air mixtures.

The latter half of the book, in the main, deals with flow through nozzles, pipes and compressor and turbine blading. In this section, the usual one-dimensional thermodynamic treatment is adopted and extended in some cases, but there are some features that cannot escape criticism. In dealing with the flow through nozzles, a qualitative discourse on oblique shock waves in supersonic flow is introduced rather abruptly with little or no introduction to shock wave theory generally. The extension of pipe flow theory to compressible fluids could well have been shortened to allow for the treatment of pipe flow with heat addition, thus affording an introduction to combustion chamber theory. Finally, the chapters on flow in compressor and turbine blading, although introducing the radial equilibrium concept, barely mention the all-important and extensive aerodynamic theory on which modern designs are based. The author could well have omitted from this latter section of the book, some of the more extended thermodynamic analysis in order to include, at least, an introduction to the aerodynamic side of the subject.

Summarising, therefore, the book, on the whole, can be recommended as a useful exposition of the fundamental thermodynamics of gas turbine technology. It stops short at that, however, and a reader wishing to cover the whole field of fundamental gas turbine technology must be prepared for equally extensive and more difficult studies on other aspects of the subject.—S.J.M.

I FLEW WITH THE BIRDS. Harald Penrose. Country Life Ltd., London. 1949. 18s. net. 206 pp. 23 illustrations.

Here is the poetry of flight told in the swaying, lilting, melodious, soaring prose of a master pilot who knows when he has met his own masters of the air, the heron and the teal, the lapwing and the gull, the swift and the swan, " the black brent as they flew westward under the moon."

Harald Penrose has written a book which makes one regret a little that he became a famous test pilot instead of treading the paths of literature, for he has a flair for the right word, the illuminating phrase, and the descriptive touch of deep-felt experience which would have taken him far in the ranks of authorship. Yet, perhaps, it is as well that the air became his love, or else one might never have had the pleasure of reading,

> " As the aeroplane rushed by, the lapwings twinkled like lamps signalling Morse. There was a rhythmic repetition of black and white, and suddenly a long flash of white as the birds tilted and turned sharply away."

Or,

> " In the span of ninety minutes we had seen the lag in spring between the extreme ends of England. Was there then a miracle in the waiting of a bird, or the impulse that prompted it to start from farthest Africa? Sufficient for me that in the human heart the same unrest will tug at spring; a bitter-sweet happiness that cannot be fully analysed, nor need be."

The author is observant to a degree and he makes many comments which will be of value to those who are interested in soaring and gliding as well as bird flight. He noted mallards flying at 1,600 feet in formations of nine, in groups of five and four, each led by a drake. One evening he watched the massing of starlings in Cornwall, and calculated there must have been half a million in a single hour's massing flight.

But read for yourself. Read of the Flight of the Swans, of the Peregrine Saga. of Gulls above Wessex.

And if you have the air in your blood you will say with the author " And then I recollected that everywhere beneath the husk was life, and in a few more minutes I would land, be talking and laughing with my friends as we sat by the fire—and the widgeon and the empty sea, the loneliness as well as the adventure of flying, would seem no more than a dream remembered on waking."

A glorious book of the air.—J.L.P.

THE HELICOPTER OR ANYTHING A HORSE CAN DO. Colonel H. F. Gregory. Allen and Unwin, London. 1949. 18s. net. 271 pp. 18 illustrations.

This book was originally published in America in 1944 under the title *Anything a Horse Can Do. The Story of the Helicopter.*

Few are better fitted to tell the tale of the development of rotating wing aircraft, and in particular of the Helicopter, in America than Frank Gregory, since he was intimately concerned with that development first as the officer assigned to the N.A.C.A. to fly the first Autogiros purchased by the Army Air Corps in 1936, and later, until the end of the war, as the officer in charge of Helicopter Development at Wright Field.

The edition under review is allegedly revised for sale in this country, but the "revision" consists merely in the deletion of one paragraph, the change of "airplane" to "aeroplane" throughout, a correction due to the death in the meantime of Orville Wright, and in the addition of a new chapter "European Development."

From the dust-cover, anyone who picks up the volume will expect to find that it is some sort of primer enabling one to "learn why the Helicopter flies and the technique of piloting the machine." The author never intended it to be anything of the sort. It is, in fact, except for the opening chapters, a record of his personal association with the American Rotating Wing Developments. The first three chapters give an adequate review of the early work on the Autogiro and Helicopter, though there are a few errors, possibly misprints, in dates and names.

The main autobiographical part of the book is extremely readable, and with its wealth of anecdotes is most entertaining. It will prove of interest to the non-technical reader in giving him an excellent picture of how the Helicopter was brought to its present stage of development and how it is being used by operators. Even though comment has been made of the publishers' presentation of the volume as a sort of text book, none-the-less the two semi-technical chapters are written with great clarity and are models of how technical subjects should be presented for popular reading. "The How and Why" is a lucid and easily understood explanation of how the Gyroplane and Helicopter sustain themselves and how they are controlled, and "Let's take a Ride in the X.R.4" is a Helicopter flight training manual in miniature. It is presented so well that the publishers' over-enthusiastic "blurb" on the dust-cover is almost justified.

As to the added chapter "European Development" one feels that one would by far have preferred the book to have been reprinted exactly as Frank Gregory wrote it. If it was felt that the wholly American character required a little tampering by at least some reference to the fact that Europe is by no means behind in Helicopter Development, then more care should have been taken to get the facts right. As it stands this chapter is full of inaccuracies.

The book is well printed on good paper, but one asks why some of the original photographs have been deleted? Surely such historic Helicopters as the Breguet co-axial type of 1936 and the Focke Achgelis Fa.61, the first practical Helicopter, are worthy of a place in any historical review of Helicopter Development?

As has been said, this reviewer feels that it would have been better to leave well alone and to have simply reprinted the book in its original form, but in spite of the criticisms the publication in this country is well worth while since the original is probably known to very few. The book should prove of fascinating interest to all those who realise that the Helicopter has come to stay and who want to know more about it. More than that, any technician who picks it up will surely be so enthralled that he will not leave it until he has read it through from cover to cover.—R.N.L.

CORRESPONDENCE

DESIGN OF PROPELLERS

In their paper "The Design of Propellers" (JOURNAL August 1949), Messrs. Gardiner and Mullin stated that engine "choking" could be experienced when throttles were opened with propellers in reverse pitch, and indicated that this was because of the abnormal air flow into the air intakes, and the slow-running characteristics of the engines, under those conditions.

I believe that these difficulties are limited to engines whose fuel metering is controlled by indirect means (*e.g.* speed-density pumps), that the trouble is starving rather than choking, and that it does not occur in the idling range, but only after the throttles have been opened. This last point can be established to one's own satisfaction, during a reversed landing, by actuating the pitch change but not opening the throttles. After all, most engine air intakes are located at a very small radius on the propellers, where the air flow is so disturbed at low air speeds that it makes little difference whether the propeller blades are in forward or reverse pitch.

The reason for the stalling lies in the fact that current propellers are not governed while in reverse pitch; consequently, while attempting to accelerate the engines at air speeds well above that for which the reverse-pitch setting is calculated, the engine manifold pressures are much higher than those which occur during forward-pitch operation at the same low rotational speeds. Under these conditions (low r.p.m. and high m.a.p.), the usual large exhaust valve overlap permits a loss of induction air, which the fuel metering system has no means of finding out about; thus, with a given amount of fuel and too much air, the mixture strength becomes too low, and the engines stall.

The ideal solution to this, and to less serious problems connected with reversing, appears to lie in the provision of "constant-speed" governing over the range between the reverse stop and the low (forward) pitch stop.

C. D. Long, *Associate Fellow*, Cartierville, Quebec.

We have read Mr. Long's letter with considerable interest and are in general agreement with his statements.

It certainly appears that our choice of the word "choking" was made without the realisation that it specifically implied engine failure due to an over-rich mixture. As Mr. Long states, the engine stalling during landing brake operation is due to lack of petrol rather than lack of air.

While a propeller which was governed in reverse pitch would alleviate this difficulty, it would also greatly increase design problems.

It is not even certain that a propeller in reverse pitch can be successfully governed since its blades will be completely stalled in this condition and therefore difficult to control.

At the present time the difficulty of engine stalling is being overcome by choosing fine braking blade angles and restricting the throttle opening which can be used in negative pitch.

Since the braking drag at the beginning of the landing run is much more sensitive to r.p.m. than to power, the reduction in braking effect due to this procedure is small and unimportant.

G. C. I. Gardiner, *Associate Fellow.*
T. Mullin, *Associate Fellow.*

INDUSTRIAL WIND TUNNELS

The paper by Mr. Ellis on " Industrial Wind Tunnels " (JOURNAL, August 1949) appeals both in practical approach and economic appreciation.

More might well have been said concerning the water tunnel which can work at approximately one twelfth of the free stream velocity of the atmospheric wind tunnel for constant model dimensions, fluid temperature and Reynolds number. The cavitation method quoted by Mr. Ellis as used in (German?) water tunnels is, in principle, similar to that used by the present writer as far back as 1937-38 in the simple examination of wing/body junctions and windscreens for both open and closed cockpits.

Part models for use with the cavitation method were run submerged in a bath of water, the interior of the model being vented to atmosphere. A windscreen having a clear-view slot along the front panel and down the full depth of both side panels was developed in this way. Subsequent check on a full scale mock-up screen attached to an aircraft stationary on the ground, with engine running at full throttle to provide the requisite wind, confirmed both the draught-free nature of the slot and the contour of the flow shed from the trailing edges of the screen panels.

A great deal can be learned, apparently, from the use of dynamically similar models run as free gliders in water. Such phenomena as stability and control, spinning, development of the stall and flow over a swept wing can be studied in a convincing and relatively unhurried manner. It must be admitted at once that, so far, information so obtained has not been checked, either by orthodox tests (at an acceptable Reynolds number) in the wind tunnel or from full scale flight.

The water models, of necessity, are relatively dense which obviously facilitates robust construction. If the part of the model which is being investigated—the tail unit for example—is made from a material having a specific gravity of about one, it is possible to change its size or position without affecting either the weight or the balance of the submerged model. Some correction to the model for change of inertia still has to be made because of change of mass.

C. G. W. Ebbutt, *Associate Fellow*

an appreciation

THE COUNCIL OF THE ROYAL AERONAUTICAL SOCIETY WISH TO THANK THOSE COMPANIES WHO, BY THEIR GENEROUS CO-OPERATION, HAVE DONE SO MUCH TO HELP IN THE PRODUCTION OF THE JOURNAL

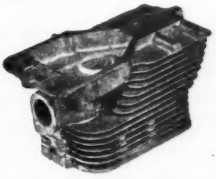
ACCLES & POLLOCK LIMITED

A&P
Make it with Tubes

AIRWORK LIMITED

AIRWORK
LIMITED

AEROPLANE & MOTOR ALUMINIUM CASTINGS LTD.



ALUMINIUM GRAVITY DIE CAST CYLINDER HEAD

ARMSTRONG SIDDELEY MOTORS LTD.

ARMSTRONG
SIDDELEY

AIRCRAFT MATERIALS LIMITED

AML

STRUCTURAL MATERIALS
and COMPONENTS

SIR W. G. ARMSTRONG WHITWORTH AIRCRAFT LTD.

SIR W. G.
ARMSTRONG WHITWORTH
AIRCRAFT LIMITED

AUTOMOTIVE PRODUCTS COMPANY LTD.

ALL-BRITISH Lockheed hydraulics

THE BRISTOL AEROPLANE CO., LTD.

"Bristol"

BIRMETALS LTD.

BIRMETALS

THE BRITISH ALUMINIUM CO. LTD.

BA

BLACKBURN & GENERAL AIRCRAFT LTD.

BLACKBURN & GENERAL

BROOM & WADE LTD.

"BROOMWADE"

AIR COMPRESSORS AND PNEUMATIC TOOLS

JAMES BOOTH & COMPANY LTD.

BOOTH

BIRMINGHAM

DURALUMIN

REGISTERED TRADE MARK

DOWTY EQUIPMENT LIMITED

DOWTY

UNDERCARRIAGE AND HYDRAULIC EQUIPMENT

BOULTON PAUL AIRCRAFT LTD.

BPA

DUNFORD & ELLIOTT (SHEFFIELD) LTD.

Dunelt

Special steels

FOR AIRCRAFT

DUNLOP RUBBER CO. LTD

DUNLOP

FOLLAND AIRCRAFT LIMITED

FOLLAND AIRCRAFT LTD

HAMBLE, SOUTHAMPTON

THE ENGLISH ELECTRIC COMPANY LTD.
LONDON

MANUFACTURERS OF AIRCRAFT, AIRCRAFT ELECTRICAL EQUIPMENT, WIND TUNNEL DRIVES, TEST PLANTS FOR RECIPROCATING AND TURBINE-TYPE ENGINES, SUPERCHARGERS, COMPRESSORS, ETC.

GLOSTER AIRCRAFT CO., LTD.

GLOSTER AIRCRAFT CO. LTD.

ENGLISH STEEL CORPORATION LTD.

STEEL MANUFACTURERS
ESC
ENGLISH STEEL CORPORATION LTD
SHEFFIELD

HANDLEY PAGE LIMITED

HP

THE FAIREY AVIATION COMPANY LTD.

ROTARY WING AIRCRAFT

FAIREY

HAWKER AIRCRAFT LIMITED

HAWKER

FIRTH-VICKERS STAINLESS STEELS LTD.

"Staynbrite" Steel

FIRTH-VICKERS STAINLESS STEELS LTD SHEFFIELD

THE HESTON AIRCRAFT CO., LTD.

HESTON AIRCRAFT

H. M. HOBSON LTD.

Hobson

INTEGRAL LIMITED

INTEGRAL
HYDRAULIC PUMPS AND EQUIPMENT

F. A. HUGHES & CO., LIMITED

Distributors of
ELEKTRON
REGISTERED TRADE MARK
MAGNESIUM ALLOYS

IRVING AIR CHUTE OF GREAT BRITAIN LTD.

AIR CHUTES
IRVIN

HENRY HUGHES & SON LTD.

REGISTERED TRADE MARK
HUSUN
HENRY HUGHES & SON LTD. LONDON

K.L.G. SPARKING PLUGS LTD.

K·L·G
SPARKING PLUGS AND IGNITION EQUIPMENT

THE HUGHES-JOHNSON STAMPINGS LTD.

JH

KELVIN BOTTOMLEY & BAIRD LTD.

KBB

IMPERIAL CHEMICAL INDUSTRIES LTD.
(METALS DIVISION)

ICI

LIGHT-METAL FORGINGS LTD.

LMF

LODGE PLUGS LIMITED

LODGE
PLUGS

PERCIVAL AIRCRAFT LIMITED

MOLLART ENGINEERING CO. LTD.

ME

Members of the Gauge & Tool Makers' Association

PETO & RADFORD

DAGENITE
AIRCRAFT BATTERIES

THE MOND NICKEL COMPANY LTD.

THE PULSOMETER ENGINEERING CO. LTD.

D. NAPIER & SON LIMITED

A. V. ROE & COMPANY LIMITED

THE PALMER TYRE LIMITED

'First in the Air'

Palmer

THE PALMER TYRE LIMITED
Herga House, Vincent Square, London, S.W.1.

ROLLS-ROYCE LIMITED

ROLLS-ROYCE
AERO-ENGINES

ROTAX LIMITED

ROTAX
AIRCRAFT ELECTRICAL ENGINEERS

SKYHI LIMITED

SKYHI

ROTOL LIMITED

ROTOL

SMITHS AIRCRAFT INSTRUMENTS LTD.

SMITHS

SANGAMO WESTON LTD.

AIRCRAFT Weston INSTRUMENTS

THE SPERRY GYROSCOPE COMPANY LTD.

SPERRY

SERCK RADIATORS LIMITED

SERCK

THE UNITED STEEL COMPANIES LIMITED

"FLYING FOX"
ELECTRIC STEELS

S. FOX & CO. LTD. SHEFFIELD

SHORT BROTHERS & HARLAND LIMITED

Shorts
Established 1908
THE FIRST MANUFACTURERS
OF AIRCRAFT IN THE WORLD

VOKES LIMITED

AMBER CROSS
TRADE MARK
Symbol of complete protection by Vokes Filters

WESTLAND AIRCRAFT LIMITED

WESTLAND AIRCRAFT LIMITED
Yeovil, Somerset

HENRY WIGGIN & COMPANY LTD.

For High Quality
NICKEL ALLOYS

A. C. WICKMAN LIMITED

A.C. Wickman LIMITED
COVENTRY • ENGLAND •

SPECIALISTS IN MACHINE TOOLS & SMALL TOOLS FOR THE AIRCRAFT INDUSTRY

WILLIAMSON MANUFACTURING CO., LTD.

The Journal is published monthly at the Offices of the Society, 4 Hamilton Place, Piccadilly, London, W1. None of the papers or paragraphs must be taken as expressing the opinion of the Council of The Royal Aeronautical Society unless such is definitely stated to be the case. Subscriptions per annum, £4 13 0 including postage; Single Numbers 7/6 or 7/9 post free. All communications for publication or Advertisements in the Journal, or on general matters affecting the Society should be addressed to—The Secretary, J. Laurence Pritchard, 4 Hamilton Place, W1. The Society's Bankers are Messrs. Coutts & Co.

Telephone: Grosvenor 3515 (5 lines) Telegraphic Address: Didaskalos, Audley, London.

DIRECTORY OF ADVERTISERS

ACCLES & POLLOCK LTD.	Paddock Works, Oldbury, Birmingham	Broadwell 1500
AEROPLANE & MOTOR ALUMINIUM CASTINGS LTD.	Wood Lane, Erdington, Birmingham	Erdington 2207-9
AIRCRAFT MATERIALS LTD.	Midland Road, London, N.W.1	Euston 6151
AIRSPEED LTD.	The Airport, Portsmouth	Portsmouth 74631
AIRWORK LTD.	15 Chesterfield Street, London, W.1	Grosvenor 4841
ALBRIGHT & WILSON LTD.	49 Park Lane, London, W.1	Grosvenor 1311
ALVIS LTD.	Holyhead Road, Coventry	Coventry 5501
ARMSTRONG SIDDELEY MOTORS LTD.	Parkside, Coventry	Coventry 4061
ARMSTRONG WHITWORTH AIRCRAFT, SIR W. G., LTD.	Whitley, Coventry	Coventry 61061-4
AUTOMOTIVE PRODUCTS CO. LTD.	Tachbrook Road, Leamington Spa	Leamington Spa 1700
BIRMETALS LTD.	Woodgate Works, Quinton, Birmingham, 32	Woodgate 2253
BLACKBURN AND GENERAL AIRCRAFT LTD.	Head Office: Brough, E. Yorks.	Brough 121
	Feltham Factory: Feltham, Middlesex	Feltham 3636
	London Office: 11 Upper Grosvenor Street, W.1	Grosvenor 3813
BOOTH, JAMES & CO. LTD.	Argyle Street Works, Nechells, Birmingham, 7	Birmingham E. 1221
BOULTON PAUL AIRCRAFT LTD.	Wolverhampton, Staffs.	Fordhouses 3191
BRISTOL AEROPLANE CO. LTD., THE	Filton House, Bristol	Bristol 48051
BRITISH ALUMINIUM CO. LTD.	Salisbury House, London Wall, E.C.2	Clerkenwell 3494
BRITISH BELTING AND ASBESTOS LTD.	Cleckheaton, Yorks.	Cleckheaton 800
	59 Southwark Street, London, S.E.1	Hop. 0192
BRITISH MESSIER LTD.	Cheltenham Road East, Gloucester	Churchdown 3281
BRITISH OVERSEAS AIRWAYS CORPORATION	Headquarters: Stratton House, Stratton Street, W.1	Mayfair 6611
	Traffic Enquiries: Airways Terminal, Buckingham Palace Road, S.W.1	Victoria 2323
BRITISH WIRE PRODUCTS LTD.	Worcester Road, Stourport-on-Severn	Stourport 240
BROOM & WADE LTD.	High Wycombe, Bucks.	High Wycombe 1630
DE HAVILLAND AIRCRAFT CO. LTD., THE	Hatfield Aerodrome, Herts.	Hatfield 2345
DOWTY EQUIPMENT LTD.	Cheltenham, Gloucester	Cheltenham 53471
DUNFORD & ELLIOTT (SHEFFIELD) LTD.	Attercliffe Wharf Works, Sheffield, 9	Sheffield 41121-4
DUNLOP RUBBER CO. LTD.	Fort Dunlop, Erdington, Birmingham, 24	Erdington 2121
ELECTRO-HYDRAULICS LTD.	Liverpool Road, Warrington	Warrington 2244
ENGLISH ELECTRIC CO. LTD.	Stafford	Stafford 700
ENGLISH STEEL CORPORATION LTD.	Vickers Works, Sheffield	Sheffield 41071
FAIREY AVIATION CO. LTD.	Hayes, Middlesex	Hayes 3800
FIRTH, THOS. AND JOHN BROWN LTD.	Atlas and Norfolk Works, Sheffield, 1	Sheffield 20081, 26491
FIRTH-VICKERS STAINLESS STEELS LTD.	Staybrite Works, Sheffield	Sheffield 42051
FOLLAND AIRCRAFT LTD.	Hamble, Southampton, Hants.	Hamble 3191
GLOSTER AIRCRAFT CO. LTD.	Gloster Works and Aerodrome, Hucclecote, Glos.	Gloucester 66294
GRAVINER MANUFACTURING CO. LTD.	(Aircraft Division Sales Dept.), Poyle Mill Works, Colnbrook, Bucks.	Colnbrook 48-49
HANDLEY PAGE LTD.	Cricklewood, London, N.W.2	Gladstone 8000
HAWKER AIRCRAFT LTD.	Canbury Park Road, Kingston-on-Thames	Kingston 1044
HESTON AIRCRAFT CO. LTD., THE	Heston Airport, Middlesex	Southall 2321
HIGH DUTY ALLOYS LTD.	Slough, Bucks.	Slough 21201
HOBSON, H. M., LTD.	Hobson Works, Fordhouses, Wolverhampton	Fordhouses 2266
HUGHES, F. A., & CO. LTD.	Bath House, 82 Piccadilly, London, W.1	Grosvenor 6300
HUGHES, HENRY & SON LTD.	Husun Works, New North Road, Barkingside, Essex	Hainault 2601
HUGHES-JOHNSON STAMPINGS LTD., THE	Langley Green, Birmingham	Broadwell 1361
ILIFFE AND SONS LTD.	Dorset House, Stamford Street, London, S.E.1	Waterloo 3333
IMPERIAL CHEMICAL INDUSTRIES LTD. (METALS DIVISION)	Kynoch Works, Witton, Birmingham, 6	Birchfield 4848
INTEGRAL LTD.	Cousins Street, Dudley Road, Wolverhampton	Wolverhampton 24984
IRVING AIR CHUTE OF GREAT BRITAIN LTD.	Icknield Way, Letchworth, Herts.	Letchworth 888
K.L.G. SPARKING PLUGS LTD.	Putney Vale, London, S.W.15	Putney 2671
KELVIN, BOTTOMLEY & BAIRD LTD.	Kelvin Avenue, Hillingdon, Glasgow, S.W.2	Halfway 3331
	Kelvin Works, Basingstoke	Basingstoke 690
LIGHT-METAL FORGINGS LTD.	Oldbury, Birmingham	Broadwell 1152
LODGE PLUGS LTD.	Rugby	Rugby 2076
MARSTON EXCELSIOR LTD.	Wolverhampton	Fordhouses (W'ton) 2181
	49/59 Armley Road, Leeds, 12	Leeds 37351 Armley 38081-5
MOLLART ENGINEERING CO. LTD.	Kingston By-Pass, Surbiton, Surrey	Elmbridge 3352-4
MOND NICKEL CO. LTD., THE	Grosvenor House, Park Lane, London, W.1	Grosvenor 4131

DIRECTORY OF ADVERTISERS

NAPIER D., & SON LTD.	Acton, London, W.3	Shepherds Bush 1226
PALMER TYRE LTD., THE	Herga House, Vincent Square, London, S.W.1 ..	Victoria 8323
PERCIVAL AIRCRAFT LTD.	Luton Airport, Luton, Beds.	Luton 2960
PETO & RADFORD	Chequers Lane, Dagenham, Essex	Rainham 34
PITMAN, SIR ISAAC & SONS LTD.	Parker Street, Kingsway, London, W.C.2	Holborn 9791
PULSOMETER ENGINEERING CO. LTD., THE	Nine Elms Iron Works, Reading.	Tilehurst 67182-4
	39 Victoria Street, London, S.W.1	
QANTAS EMPIRE AIRWAYS	c/o British Overseas Airways Corporation, Airways Terminus, Buckingham Palace Road, S.W.1 ..	Victoria 3126
The R.A.F. Quarterly	Gale & Polden Ltd., Ideal House, Argyll Street, W.1	Gerrard 4171
ROE, A. V., & CO. LTD.	Greengate, Middleton, Manchester	Failsworth 2020-2039
ROLLS-ROYCE LTD.	Derby	Derby 2424
ROTAX LTD.	Willesden Junction, London, N.W.10	Elgar 7777
ROTOL LTD.	Cheltenham Road, Gloucester	Gloucester 24431
SANGAMO WESTON LTD.	Great Cambridge Road, Enfield, Middlesex	Enfield 3434 & 1242
SAUNDERS-ROE LTD.	Head Office: Osborne, E. Cowes, Isle of Wight ..	Cowes 445
	London Office: 40 Parliament St., Westminster, S.W.1	Whitehall 7271
SERCK RADIATORS LTD.	Warwick Road, Birmingham, 11	Victoria 0531
SHELL-MEX AND B.P. LTD.	Shell-Mex House, Strand, London, W.C.2	Temple Bar 1234
SHORT BROTHERS AND HARLAND LTD. ..	Seaplane Works, Queen's Island, Belfast	Belfast 58444
SKYHI LTD.	"Skyhi" Works, Worton Road, Isleworth, Middlesex	Hounslow 2211
SMITHS AIRCRAFT INSTRUMENTS LTD. ..	Cricklewood Works, London, N.W.3	Gladstone 3333
SPERRY GYROSCOPE CO. LTD., THE	Great West Road, Brentford, Middlesex	Ealing 6771
TEMPLE PRESS LTD.	Bowling Green Lane, London, E.C.1	Terminus 3636
UNITED STEEL COMPANIES LTD., THE ..	17 Westbourne Road, Sheffield, 10	Sheffield 60081
VICKERS-ARMSTRONGS LTD.	Vickers House, Broadway, Westminster, S.W.1 ..	Abbey 7777
	Weybridge Works, Weybridge, Surrey	Byfleet 240-243
	Supermarine Works, Hursley Park, Winchester, Hants.	Chandlersford 2251
VOKES LTD.	Henley Park, near Guildford, Surrey	Guildford 62861
WAKEFIELD, C. C., & CO. LTD.	46 Grosvenor Street, London, W.1	Mayfair 9232
WESTLAND AIRCRAFT LTD.	Yeovil, Somerset	Yeovil 1100
WICKMAN, A. C., LTD.	Tile Hill, Coventry	Tile Hill 66271
WIGGIN, HENRY, & CO. LTD.	Wiggin Street, Birmingham	Edgbaston 2245
WILLIAMSON MANUFACTURING CO. LTD. ..	Litchfield Gardens, Willesden Green, N.W.10	Willesden 0073-0075
YORKSHIRE ENGINEERING SUPPLIES LTD. ..	Bronze Foundries, Upper Wortley Road, Leeds, 12 ..	Leeds 38234 & 38291

THE ROYAL AERONAUTICAL SOCIETY
4 HAMILTON PLACE, PICCADILLY, LONDON, W.1. GROSVENOR 3515-9

NOTICES NOVEMBER 1949

CONTENTS OF NOVEMBER JOURNAL

Fifth British Commonwealth and Empire Lecture—Inter-City Transport Development on the Commonwealth Routes, by E. H. Atkin, B.Sc., F.R.Ae.S.
The Design of Compression Structures for Minimum Weight, by D. J. Farrar, M.A., A.F.R.Ae.S.
Notes on the Opening Behaviour and the Opening Forces of Parachutes, by F. O'Hara, M.A.
Aircraft Defect Report Procedure, by A. H. Greenwood, A.R.Ae.S.
Reviews.
Correspondence.

The Council have set aside an annual sum of £250 for the award of premiums for papers published in the Journal and hope that members and non-members of the Society will contribute papers on their own special subjects.

THE AERONAUTICAL QUARTERLY

Part III of " The Aeronautical Quarterly " will be published in November. Copies will be obtainable towards the end of the month from the offices of the Society, 4 Hamilton Place, W.1, at 7s. 9d. each to members of the Society, post paid, or 10s. 3d. each to non-members, post paid.

The contents of Part III will be:—

Surging of Axial Compressors	H. Pearson and T. Bowmer
Strain Measurement by X-Ray Diffraction Methods	G. B. Greenough
Buckling of a Longitudinally Stiffened Flat Panel	H. L. Cox and J. R. Riddell
Approximate Calculation of the Laminar Boundary Layer	B. Thwaites

Copies are still available of Parts II and I.

The contents of Part II are:—

Displacements of a Linear Elastic System under a Given Transient Load	D. Williams
Skin Friction in the Laminar Boundary Layer in Compressible Flow	A. D. Young
The Measurement of Gas Turbine Combustion Efficiency by Gas Analysis	L. J. Richards and J. C. Street
A Simplified Theory of " Simple Waves "	A. Ghaffari

The contents of Part I are:—

Control Reversal Effects on Swept-Back Wings	H. Templeton
Calculation of Downwash Behind a Supersonic Wing ..	G. N. Ward
Estimation of the Effects of a Parameter Change on the Roots of Stability Equations	K. Mitchell
Flutter of Systems with Many Freedoms	W. J. Duncan
Note on Propeller-Turbine Reduction Methods	E. C. Pike
Determination of the Drag of Jet-Propelled Aircraft in Flight	G. W. Trevelyan and D. R. Blundell
Notes on the Linear Theory of Incompressible Flow Round Symmetrical Swept-back Wings at Zero Lift	F. Ursell

The special attention of members is drawn to the fact that a strictly limited edition only of " The Aeronautical Quarterly " is printed and numbers cannot be reprinted in any circumstances.

HELICOPTER ASSOCIATION LECTURE

The next lecture of the Helicopter Association will be given by Professor A. R. Collar, M.A., D.Sc., F.R.Ae.S., on " Some Speculations on the Aeroelastic Problems of Rotary Wing Systems " in the Library of the Society at 2.30 p.m. on Saturday, 26th November 1949. The Helicopter Association have kindly invited members of the Society to attend this lecture if they wish.

Tea is available after the lecture at 1s. 6d. per head.

COMMONWEALTH FUND FELLOWSHIPS

The attention of members is drawn to the four Commonwealth Fund Fellowships, particulars of which are as follows:—

I.—Purpose of the Fellowships

The Commonwealth Fund of New York, a philanthropic foundation existing since 1918 and supported by endowment from the late Mrs. Stephen V. Harkness and the late Mr. Edward S. Harkness, has established for British subjects a number of Fellowships tenable in the United States. In creating these Commonwealth Fund Fellowships the Directors of the Fund have been impelled by a belief in the value of international opportunities for education and travel, and by a conviction that mutual amity and understanding between Great Britain and the United States will thereby be promoted. The Fellowships are under the patronage of His Majesty King George VI.

II.—Eligibility

There are four categories of Fellowships:

(1) Ordinary Fellowships.—Open to candidates who (*a*) are over 23 and under 35 years of age on 1st September of the year of award; and (*b*) have not worked or studied in any educational or research institution in the United States for one or more academic years. Candidates who are domiciled in the United Kingdom of Great Britain and Northern Ireland must be degree graduates of a recognised university therein. Candidates not domiciled in the United Kingdom must be graduates of a recognised university in Australia, New Zealand, or South Africa, and must have studied at, although not necessarily graduated from, a university in the United Kingdom. Twenty Ordinary Fellowships will be offered in 1950.

(2) Home Civil Service Fellowships.—Open to candidates holding permanent appointments in the higher ranks of the Civil Service in Great Britain. Three Fellowships will be offered in 1950 for the administrative grades and two Fellowships for the technical and professional grades.

(3) Dominion Civil Service Fellowships.—Open to candidates who hold appointments overseas under the Governments of Australia, New Zealand and South Africa. Five Fellowships will be offered in 1950.

(4) Colonial Civil Service Fellowships.—Open to candidates who hold appointments under the Governments of the British Colonies, Protectorates, and Trust Territories. Two Fellowships will be offered in 1950.

All categories of Fellowships are now open to women.

Full particulars may be obtained from the Secretary of the Committee of Award, 35 Portman Square, London, W.1.

MEMBERS' NEW APPOINTMENTS

The following member has recently taken up a new appointment:—

Mr. P. G. Masefield, *Fellow*—Chief Executive, British European Airways.

THE SOCIETY'S LECTURES

The Council have decided to extend the Society's lecture programme to include subjects of specialised interest ranging over the many different branches of aeronautical science and engineering.

To interest the specialist and to assist the junior members of the Society a series of special lectures (called Section Lectures) are being arranged in the Society's library. Five of these additional lectures will be held in the Autumn Session and upon their success will depend the extension of the scheme. The Section Lectures will be of two main types:—

(*a*) An exposition on a subject by an expert on the lines of a University Lecture occupying 40 to 50 minutes, followed by a discussion in which the audience will ask questions rather than make additional contributions to the subject. No pre-prints will be available normally for this type of lecture.
All the Section Lectures arranged for the Autumn Session are of this type.

(*b*) A " Discussion Evening " which will be opened by a lecturer presenting the main points of his paper in not more than 10 minutes, followed by a general discussion.

If the success of the Section Lecture is established, a number of these will be read out of London.

Although all Main Society Lectures will continue to be published in the JOURNAL it is not proposed that the Section lectures or the Discussions should automatically be published.

LECTURE SESSION, AUTUMN 1949—MAIN LECTURES

(*To be held at 6 p.m. at the Institution of Civil Engineers, Gt. George Street, S.W.1, unless otherwise stated. Tea will be served at 5.30 p.m.*)

Thursday, 24th November 1949—AT BRISTOL—A Review of Aerodynamic Cleanness, E. J. Richards, M.A., A.F.R.Ae.S.
(*At 7.15 p.m. at the Royal Fort Physics Laboratory, Bristol*)

Thursday, 1st December 1949—The Weight Aspect in Aircraft Design, L. W. Rosenthal, A.F.R.Ae.S.

Thursday, 15th December 1949—JOINT LECTURE WITH THE INSTITUTE OF NAVIGATION—Navigational Systems and Instrument Aids, Dr. D. E. Adams, B.Sc., A.Inst.P., and Dr. A. N. Uttley, B.Sc., Ph.D.

LECTURE SESSION, AUTUMN 1949—SECTION LECTURES

(*To be held at 7 p.m. in the Library of the Society, at 4 Hamilton Place, W.1*)

Tuesday, 22nd November 1949—The Design and Development of Engine-Driven Gearboxes, G. W. Bubb, A.F.R.Ae.S.

Tuesday, 6th December 1949—The Design of Tail Pipes for Jet Engines Including Re-Heat, J. L. Edwards, B.Sc., A.M.I.Mech.E.

PROCEEDINGS OF SECOND AERONAUTICAL CONFERENCE

The Proceedings of the Second Anglo-American Aeronautical Conference, containing the 23 papers read by British and American Lecturers at the Technical Sessions in New York from 24th-26th May 1949, are to be published in one Volume by the Institute of the Aeronautical Sciences. It is hoped that the Proceedings will be ready about January 1950. The price has been fixed by the Institute at 15 dollars.

Copies may be ordered through the Society and it will greatly help both the Society and the Institute if members will place their orders for the Proceedings as quickly as possible.

GRADUATE AND STUDENT COMMITTEE

Following the decision of Council to make the Graduate and Student Section Committee a Committee of Council, a new Committee has been elected of which three members have been appointed by Council and six by the Section.

The members of the Committee chosen to serve for the remainder of the 1949-50 Session are:—

Council Representatives: S. Scott Hall, *Fellow* (P.D.T.D. (A) M.O.S.)
A. V. Cleaver, *Associate* (de Havilland Engine Co. Ltd.)
J. W. F. Housego, *Graduate* (Handley Page Ltd.)

Section Representatives: M. K. Bowden, *Student* (Northampton Engineering College)
M. C. Campion, *Graduate* (Bristol Aeroplane Co. Ltd.)
P. T. Fink, *Graduate* (Imperial College)
J. C. Gibbings, *Graduate* (Queen Mary College)
J. G. Roxburgh, *Graduate* (Handley Page (Reading) Ltd.)
A. Stanbrook, *Student* (Fairey Aviation Co. Ltd.)

All six Section representatives are members of the retiring Graduate and Student Section Committee.

GRADUATE AND STUDENT SECTION

LECTURES

Tuesday, 15th November 1949—Visualisation of Air Flow at High Speeds, A. D. Young, A.F.R.Ae.S., of the College of Aeronautics.

Summary of Lecture:—

Variations of the density of the medium through which light passes affect the speed of light, and in consequence may alter its direction. This fact is the key to the methods used to explore optically the characteristics of air flow at high speeds. The most important of these are the shadowgraph, Schlieren and interferometer methods. The basic principles of these methods, the more important practical features of their installations, their spheres of application and sensitivity are discussed and illustrated with slides.

Thursday, 8th December 1949—Bonding of Aircraft Materials with Synthetic Adhesives, C. J. Moss, B.Sc., of Aero-Research Ltd.

Lectures will be held in the Library at 4 Hamilton Place, W.1, at 7.30 p.m. The Library will not be open until 7 p.m.

BRANCH LECTURES—AUTUMN SESSION 1949

BELFAST BRANCH

Tuesday, 22nd November 1949—Lecturettes and Films.

Tuesday, 13th December 1949—Fatigue of Metallic Materials, Major P. L. Teed, A.F.R.Ae.S.

Tuesday, 24th January 1950—Recent Developments in Aircraft Production Engineering, Professor J. V. Connolly, B.Eng., F.R.Ae.S.

In the Central Hall, College of Technology, Belfast, at 7 p.m.

BIRMINGHAM BRANCH

Friday, 25th November 1949—The Investigation of Aircraft Accidents, Air Commodore Vernon S. Brown, C.B., O.B.E., M.A., F.R.Ae.S.

Friday, 6th January 1950—Annual Dinner—*at the White Horse Hotel.*

Meetings are usually held at the Birmingham Chamber of Commerce at 7.30 p.m.

BRISTOL BRANCH

Wednesday, 9th November 1949—One thousand Miles an Hour? Professor G. T. R. Hill, M.C., M.Sc., F.R.Ae.S., M.I.Mech.E.

Thursday, 24th November 1949—Review of Aerodynamic Cleanness, E. J. Richards, M.A., B.Sc., A.F.R.Ae.S.—*MAIN SOCIETY Lecture to be held at the Royal Fort Physics Laboratory, Bristol, at 7.15 p.m.*

Monday, 5th December 1949—Rocket Propulsion and Interplanetory Flight, A. V. Cleaver, A.R.Ae.S.

In the Conference Room, Bristol Aeroplane Co. Ltd., Filton House, at 6 p.m., unless otherwise stated.

BROUGH BRANCH

Wednesday, 16th November 1949—Stiffness and Strength, Professor A. R. Collar, M.A., D.Sc., F.R.Ae.S.

Wednesday, 14th December 1949—Practical Problems in the Design and Operation of Naval Aircraft, Lt.-Cdr. E. M. Brown, O.B.E., D.F.C., R.N.

Wednesday, 11th January 1950—Members' Lecturette Night.

In the Lecture Hall, Electricity Showrooms, Ferensway, Hull, at 7.30 p.m. Admission by ticket only, because of limited accommodation.

COVENTRY BRANCH

Wednesday 16th November 1949—Aircraft Structures, Dr. P. B. Walker, F.R.Ae.S.

Wednesday 14th December 1949—Film Evening on Aircraft Materials.

In the Trinity Hall (near Pool Meadow) Coventry at 7.30 p.m.

DERBY BRANCH

Monday, 5th December 1949—Annual General Meeting.

In the Welfare Hall, Rolls-Royce Ltd., Nightingale Road, Derby, at 6.15 p.m.

GLASGOW BRANCH

Tuesday, 29th November 1949—Recent Developments in Experimental Stress Analysis, Dr. Rothman.

Tuesday, 20th December 1949—Annual General Meeting.

Meetings are held in Glasgow at 7.30 p.m. Members are notified individually of the meeting place.

GLOUCESTER AND CHELTENHAM BRANCH

Thursday, 24th November 1949—*at Cheltenham*—The Investigation of Air Accidents, Air Commodore Vernon S. Brown, C.B., O.B.E., M.A., F.R.Ae.S.

Wednesday, 14th December 1949—*at Gloucester*—Problems of High Speed Flight, H. Davies, M.Sc., F.R.Ae.S.

Thursday, 12th January 1950—*at Cheltenham*—Recent Developments in Aircraft Production Engineering, Professor J. V. Connolly, B.Eng., F.R.Ae.S.

Gloucester Meetings (Wednesdays) are held in the Wheatstone Hall, City Library, Brunswick Road, at 7.30 p.m.

Cheltenham Meetings (Thursdays) are held in the Empire Hall, North Street, at 7.30 p.m.

LUTON BRANCH

Wednesday 23rd November 1949—Aeronautical Brains Trust.

Wednesday 7th December 1949—The Probable Role and Influence of Aircraft in Future Warfare, Air Marshal Sir Robert Saundby, K.B.E., C.B., M.C., D.F.C., A.F.C.

Wednesday 14th December 1949—Annual General Meeting and Presidential Address.

Meetings are usually held at the George Hotel, Luton, at 7.30 p.m.

PORTSMOUTH BRANCH

Friday, 2nd December 1949—Model Section Display.

Friday, 16th December 1949—Recent Developments in Aircraft Production Engineering, Professor J. V. Connolly, B.Eng., F.R.Ae.S.

Friday, 13th January 1950—Accident Investigation, Air Commodore Vernon S. Brown, C.B., O.B.E., M.A., F.R.Ae.S.

In the Lecture Room, Central Library, at 7 p.m.

PRESTON BRANCH

Wednesday, 7th December 1949—Icing of Aircraft, J. K. Hardy.

Thursday, 15th December 1949—Annual Dance, 8 p.m.—1 a.m. *at Worsley's Ballroom, Market Street, Preston.*

Lectures are held in the Assembly Hall, Technical College, Corporation Street, at 7.30 p.m.

READING AND DISTRICT BRANCH

Wednesday, 23rd November 1949—History of British Airships, Lord Ventry.
Wednesday, 7th December 1949—Some Experiences in 40 years of Aviation, Sir Frederick Handley Page, C.B.E., F.R.Ae.S.—*at the George Hotel, Reading.*
Meetings are held at the Abbey Gateway, Reading, at 7.30 p.m., unless otherwise stated.

SOUTHAMPTON BRANCH

Wednesday, 16th November 1949—The Role of Aircraft in War and their Probable Influence on the Future, Air Marshal Sir Robert Saundby, K.B.E., C.B., M.C., D.F.C., A.F.C.
Wednesday, 7th December 1949—Annual General Meeting. To be followed by Discussions on Selected Topics.
Wednesday, 11th January 1950—Accident Investigation, Air Commodore Vernon S. Brown, C.B., O.B.E., M.A., F.R.Ae.S.
In the Physics Lecture Theatre, University College, at 7 p.m.

WEYBRIDGE BRANCH

Wednesday, 30th November 1949—Radar and the Aircraft Which Use It, B. W. Hodlin, B.Sc., Hons.Phys.
Wednesday, 21st December 1949—Round the World in 90 days (a record of a 40,000 mile air journey), W. Courtenay, M.M., A.R.Ae.S.
Wednesday, 11th January 1950—Brains Trust.
At Vickers-Armstrongs Ltd., Weybridge Works, at 6 p.m., unless previous notice is given.

ASSOCIATE FELLOWSHIP EXAMINATION—DECEMBER 1949

The Associate Fellowship examination will be held on 19th, 20th, 21st and 22nd December 1949 at the Imperial College of Science and Technology, South Kensington. All candidates will receive a time-table and full particulars of the examination nearer the time.

SENIOR SCIENTIFIC OFFICERS

Applications for posts as SENIOR SCIENTIFIC OFFICERS for aircraft research in Structures Division, Royal Aircraft Establishment, Farnborough, are invited by the Ministry of Supply.

Candidates must be at least 26 years of age, possess a good honours degree in engineering, physics or mathematics, and have experience in the design of structures or fatigue testing of materials and structural elements. They will be required to do original research in these fields.

Posts are unestablished but carry F.S.S.U. benefits. Starting salary according to age, qualifications and experience is within the range £670-£860. Rates for women are somewhat lower.

Write quoting A267/49/GE to Technical and Scientific Register (K), York House, Kingsway, London, W.C.2, for application forms which should be returned completed by 15*th December* 1949.

CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Changes of address must be received *before the* 15*th of the month* in order to be effective for the Journal for the following month.

JOURNAL BINDING

The prices for binding of Journals are as follows:—

1948 Volume	14s. 6d.	(including packing and postage)
Previous Volumes ..	16s. 0d.	,, ,, ,, ,,
Cases for 1948 Volume	6s. 0d.	,, ,, ,, ,,

Journals should be sent direct to the Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the Offices of the Society.

Requests for cases, with remittances, should be sent to the Secretary at the Offices of the Society.

ELECTIONS

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

James Alexander Gwilym Diack (from Graduate), Philip Gerard Duff, Ronald Ferrari (from Graduate), Walter Edmund Hogsflesh (from Associate), Richard Joseph Ifield (from Associate), Bennett Isherwood (from Student), K. Ramachandran, Donald Selvey, Sidney William Henry Wood (from Graduate).

Associates

Archibald Currie Beazer, Alan Edgar Bristow, Fred Brooks, John Doherty, Hugh Kelvin Ford, Michael Eveness Haldane Grant (from Student), Llewellyn Ernest Hartridge, Herbert David Laidlaw, Maitland Robert Roper, John Vivian Stanbury.

Graduates

Robert Malcolm Allan (from Student), Roy Gregory Barnden (from Student), Leonard Stanley Davey, Kenneth James Iddon (from Student), Philip John Mitchelmore, Tadeusz Pasternak, Bernard John Preston (from Student), David Hunter Thomson, Vincent David Trimm.

Students

Stuart Grant Harris, Roy Gordon Lewer, John David Roberts, John Shields.

ACKNOWLEDGMENTS

The Council wish to acknowledge with grateful thanks the gift of the model of the first Canadian J.N.4 machine from which this type was made in Canada during the 1914-1918 War. The model was presented to Colonel David Carnegie who was a member of the Imperial Munitions Board of Canada and Ordnance Adviser to the Canadian Government and has been given to the Society by his widow Mrs. David Carnegie.

The Council also acknowledge with grateful thanks the gift of periodicals from Sir Oliver Simmonds, F.R.Ae.S., and P. Steiner, Esq.

ADDITIONS TO THE LIBRARY

Pamphlets in italics with location reference following in brackets. Books marked * or ** may not be taken out on loan.

B.b.30—Helicopter Engineering. R. A. Young. Ronald Press. 1949.
B.f.106—I flew with the Birds. H. Penrose. Country Life. 1949.
*B.g.156—Airliners. J. Stroud. Penguin Books. 1949.
**C.a.16—Extract containing "Aerostation." Encyclopedia Britannica, 3rd Edition. 1797.
E.b.141—Analytical Mechanics of Gears. E. Buckingham. McGraw Hill. 1949.
EE.c.98—Internal Combustion Engineering. A. T. J. Kersey. 3rd Edition. Blackie. 1949.
EE.c.99—Verbrennungsmotoren. F. A. F. Schmidt. Springer. 1939.
EE.h.51—Le refroidissement des turbines a gaz. J. Cornillon. Sec. d'état aux forces armées. 1949.

G.a.89—Industrial Rheology and Rheological Structures. H. Green. John Wiley. 1949.
G.e.A.121—Modern Methods for the Analysis of Aluminium Alloys. ALAR. Chapman & Hall. 1949.
G.e.J.34—Technology of Light Metals. A. van Zeerleder. Elsevier. 1949.
I.b.24—Numerical Calculus. W. E. Milne. Princeton University Press. 1949.
L.c.35—Link Trainer.
L.e.13—New Compass of the World. H. W. Weigert & others. Harrap. 1949.
*Q.d.73—List of Periodicals, etc., containing Abstracts. Royal Society. 1949.
R.f.123—Aircraft from Airship to Jet Propulsion. B. Dickson. Vickers Armstrongs. 1949.

N.A.C.A. Technical Notes

1455—*An investigation of aircraft heaters. XXXI—Summary of laboratory testing of several exhaust-gas and air heat exchangers. L. M. K. Boelter, A. G. Guibert, F. E. Romie, V. D. Sanders and J. D. Rademacher.*
1883—*Thermodynamic charts for internal-combustion-engine fluids. W. J. McCann. Revised by L. R. Turner and E. A. Bauer.*
1890—*The effect of torsional flexibility on the rolling characteristics at supersonic speeds of tapered unswept wings. W. A. Tucker and R. L. Nelson.*
1892—*Position errors of the service airspeed installations of 10 airplanes. W. Gracey.*
1893—*Effect of centrifugal force on flutter of uniform cantilever beam at subsonic speeds with application to compressor and turbine blades. A. Mendelson.*
1897—*Aerodynamic properties of cruciform-wing and body combinations at subsonic, transonic, and supersonic speeds. J. R. Spreiter.*
1900—*Preliminary investigation of the use of afterglow for visualising low-density compressible flows. T. W. Williams and J. M. Benson.*
1901—*A method for predicting the stability in roll of automatically controlled aircraft based on the experimental determination of the characteristics of an automatic pilot. R. T. Jones and L. Sternfield.*
1902—*Appraisal of method of flutter analysis based on chosen modes by comparison with experiment for cases of large mass coupling. S. D. Woolston and H. L. Runyan.*
1903—*Experimental investigation of moving pressure disturbances and shock waves and correlation with one-dimensional unsteady-flow theory. P. W. Huber, C. E. Fritton, Jr., and F. Delpino.*
1904—*Observations of icing conditions encountered in flight during 1948. W. Lewis and W. H. Hoecker, Jr.*
1905—*Experimental and theoretical studies of area suction for the control of the laminar boundary layer on a porous bronze N.A.C.A. 64A010 airfoil. D. L. Burrows, A. L. Braslow and N. Tetervin.*
1907—*An analysis of the transition of a helicopter from hovering to steady autorotative vertical descent. A. A. Nikolsky and E. Seckel.*
1908—*General algebraic method applied to control analysis of complex engine types. A. S. Boksenbom and R. Hood.*
1909—*Effect of transverse shear and rotary inertia on the natural frequency of a uniform beam. E. T. Kruszewski.*
1910—*Shear buckling of infinitely long simply supported metalite type sandwich plates. P. Seide.*
1912—*An investigation of aircraft heaters. XXXII—Measurement of thermal conductivity of air and exhaust gases between 50 degrees and 900 degrees F. L. M. K. Boelter and W. H. Sharp.*
1913—*Method of designing airfoils with prescribed velocity distributions in compressible potential flows. G. R. Costello.*
1915—*Elevated-temperature properties of several Titanium carbide based ceramels. C. G. Deutsch and W. G. Lidman.*

1916—*The effects of slideslip, aspect ratio, and mach number on the lift and pitching moment of triangular, trapezoidal and related plan forms in supersonic flow. A. L. Jones, R. M. Sorenson and E. E. Lindler.*

1917 *An analysis of the relation between horizontal temperature variations and maximum effective gust velocities in thunderstorms. H. Press and J. K. Thompson.*

1918—*Correlation of physical properties of ceramic materials with resistance to fracture by thermal shock. W. G. Lidman and A. R. Bobrowsky.*

1919—*Analytical method for determining transmission and absorption of time-dependent radiation through thick absorbers. I—Radioactivity of absorber, time-dependent. G. Allen.*

1920—*Preliminary investigation of needle bearings of* $1\frac{1}{8}$ *in. pitch diameter at speeds to* 17,000 *r.p.m. E. F. Macks.*

1921—*Approximate method for predicting form and location of detached shock waves ahead of plane or axially symmetric bodies. W. E. Moeckel.*

1922—*Two-dimensional investigation of five related N.A.C.A. airfoil sections designed for rotating-wing aircraft. R. F. Schaefer, L. K. Loftin, Jr., and E. A. Horton.*

1923—*Boundary-layer and stalling characteristics of the N.A.C.A.* 64*A*006 *airfoil section. G. B. McCullough and D. E. Gault.*

1924—*Estimation of the damping in roll of wings through the normal flight range of lift coefficient. A. Goodman and G. H. Adair.*

1925—*Line vortex theory for calculation of supersonic downwash. H. Mirel and R. C. Haefeli.*

1927—*Generalisation of turbojet-engine performance in terms of pumping characteristics. N. D. Sanders and M. Behun.*

1928—*Critical combinations of shear and direct axial stress for curved rectangular panels. M. Schildcrout and M. Stein.*

1929—*On the stability of the free laminar boundary layer between parallel streams. M. Lessen.*

1930—*An analysis of the effect of lift-drag ratio and stalling speed on landing-flare characteristics. L. C. Lovell and S. Lipson.*

1931—*Design method for two-dimensional channels for compressible flow with application to high-solidity cascades. S. Alpert.*

1932—*Two-dimensional compressible flow in centrifugal compressors with straight blades. J. D. Stanitz and G. O. Ellis.*

1933—*Investigation of spoiler ailerons for use as speed brakes or glide-path controls on two N.A.C.A.* 65*-series wings equipped with full-span slotted flaps. J. Fischel and J. M. Watson.*

1934—*Low-speed experimental investigation of a thin, faired, double-wedge airfoil section with nose and trailing-edge flaps. L. M. Rose and J. M. Altman.*

1935—*Methods for determining frequency response of engines and control systems from transient data. M. E. LaVerne and A. S. Boksenbom.*

1936—*A flight determination of the tolerable range of effective dihedral on a conventional-fighter airplane. C. J. Liddell, Jr., R. D. Van Dyke, Jr., and D. R. Heinle.*

1937—*A flight investigation of the effects of compressibility on applied gust loads. E. T. Binckley and J. Funk.*

1939—*The effects of aerodynamic brakes upon the speed characteristics of airplanes. J. D. Stephenson.*

1940—*Fundamental effects of aging on creep properties of solution-treated low-carbon N-*155 *alloy. D. N. Frey, J. W. Freeman and A. E. White.*

1941—*Attainable circulation of airfoils in cascade. A. W. Goldstein and A. Mager.*

1942—*The effect of wall friction on the strength of shock waves in tubes and hydraulic jumps in channels. C. du P. Donaldson and R. D. Sullivan.*

1944—*The reversibility theorem for thin airfoils in subsonic and supersonic flow. C. E. Brown.*

1946—*Measurements in the boundary layer of a yawed wing. A. M. Kuethe, P. B. McKee and W. H. Curry.*

1947—*Investigation of flow coefficient of circular, square, and elliptical orifices at high pressure ratios. E. E. Callaghan and D. T. Bowden.*

A.R.C. Reports and Memoranda

1900—*Aerodynamic derivatives of flexural-torsional flutter of a wing of finite span. H. M. Lyon.*
Calculations of derivatives for a wing of finite span. W. P. Jones and S. W. Skan.

2263—*An aerofoil designed to give laminar flow over the whole surface with boundary-layer suction. E. J. Richards and C. H. Burge.*

2276—*Measurements of the aerodynamic forces acting on porous screens. L. F. G. Simmons and C. F. Cowdrey.*

2278—*On the design of contractions for wind tunnels. B. Thwaites.*

2305—*Experiments on an N.A.C.A. 23021 aerofoil with a 15 per cent. Handley Page slotted flap in the compressed air tunnel. D. H. Williams and A. F. Brown.*

2320—*The theory of parachutes with cords over the canopy. G. W. H. Stevens and T. P. Johns.*

2328—*A note on cusped cavities. M. J. Lighthill.*

2339—*Preliminary investigation into the three-dimensional flow through a cascade of aerofoils. A. D. S. Carter and E. M. Cohen.*

2340—*The performance of stalled propellers. Results and analysis of some 24 ft. tunnel tests. R. J. Monaghan.*

2371—*Preliminary report on the flight measurement of aero-elastic distortion in relation to its effects on the control and longitudinal stability of a Mosquito aircraft. P. L. Bisgood and D. J. Lyons.*

2324—*Design of parachutes for large bombs. W. D. Brown and K. Harrison.*

2337—*On the behaviour of dry air in a supersonic wind tunnel. S. Goldstein.*

2339—*Preliminary investigation into the three-dimensional flow through a cascade of aerofoils. A. D. S. Carter and E . M. Cohen.*

2403—*Model tests of a " Return-flow " cooling scheme, having a wing leading-edge entry and a nose-slot exit. R. Smelt and F. Smith.*

N.A.C.A. Technical Memoranda

1161—*Wind-tunnel tests on various types of dive brakes mounted in proximity of the leading edge of the wing. B. Lattanzi and E. Bellante.*

1206—*Systematic investigation of the effects of plan form and gap between the fixed surface and control surface on simple flapped wings. Gothert and Rober.*

1209—*Experimental study of flow past turbine blades. E. Eckert and K. v. Vietinghoff-Scheel.*

1219—*The influence of the application of power during spin recovery. Multi-engine airplanes. P. Hohler.*

1225—*Test report on three- and six-component measurements on a series of tapered wings of small aspect ratio. (Partial Report: Trapezoidal Wing.) Lange/Wacke.*

1233—*Contribution to the problem of flow at high speed. C. Schmieden and K. H. Kawalki.*

1234—*Computation of thin-walled prismatic shells. V. Z. Vlasov.*

1238—*Two-dimensional wing theory in the supersonic range. H. Honl.*

1214—*Jet diffusion in proximity of a wall. D. Kuchemann.*

1221—*Experimental flights for testing of a reactor as an expedient for the termination of dangerous spins. P. Hohler and I. v. Koppen.*

1226—*On the installation of jet engine nacelles on a wing. Fourth Partial Report: Pressure distribution measurements on a sweptback wing with jet engine nacelle. R. Buschner.*

1235—*Investigation of conditions of Titanium carbonisation—IV. G. A. Meerson and Y. M. Lipkes.*

1240—*Airfoil measurements in the DVL high-speed wind tunnel (2.7-meter diameter). B. Gothert.*

1249—*Susceptibility to welding cracking, welding sensitivity, susceptibility to welding seam cracking, and test methods for these failures. K. L. Zeyen.*

N.A.C.A. Technical Reports

864—*Effects of temperature distribution and elastic properties of materials on gas-turbine-disk stresses. A. G. Holms and R. D. Faldetta.*

865—*Method for calculating wing characteristics by lifting-line theory using non-linear section lift data. J. C. Sivells and R. H. Neely.*

866—*An analysis of the full-floating journal bearing. M. C. Shaw and T. J. Nussdorfer, Jr.*

871—*Determination of elastic stresses in gas turbine disks. S. S. Manson.*

873—*High-altitude flight cooling investigation of a radial air-cooled engine. E. J. Manganiello, M. F. Valerino and E. B. Bell.*

878—*Analysis of performance of jet engine from characteristics of components. I—Aerodynamic and matching characteristics of turbine component determined with cold air. A. W. Goldstein.*

880—*Analysis of jet-propulsion-engine combustion-chamber pressure losses. I. I. Pinkel and H. Shames.*

Aeronautical Research Institute of Sweden

18—*Determination of fatigue life with stress cycles of varying amplitude. S. Luthander and G. Wallgren.*

Nationaal Luchtvaartlaboratorium, Amsterdam

1421—*The effect of spring tabs on the static longitudinal stability. A. J. Marx and J. Buhrman.*

1431—*Power operated flight controls. A. J. Marx and J. Buhrman.*

F.53—*Some remarks on the theory of near-sonic, near-parallel flow and its application to channel flow. R. Timman.*

V.1366—*A method to determine the change in flutter speed due to small changes in the mechanical system. A. I. van de Vooren.*

V.1380—*The change in flutter speed due to small variations in some aileron parameters. A. I. van de Vooren.*

V.1386—*The treatment of a tab in flutter calculations including a complete account of aerodynamic coefficients. A. I. van de Vooren.*

V.1397—*Diagrams of flutter, divergence and aileron reversal speeds for wings of a certain standard type. A. I. van de Vooren.*

S.314—*The general instability of stiffened cylindrical shells under axial compression. A. I. van de Vooren.*

College of Aeronautics

25 *The elastic stability of sandwich plates. J. H. Hunter-Tod.*

Flygtekniska Forsokstalten Ffa

27—*Some preliminary information on buckling and ultimate strength of unstiffened compression skin obtained through bending and compression tests on rectangular cross section aluminium tubes. R. A. Anderson.*

28—*Fatigue tests with stress cycles of varying amplitude. G. Wallgren.*

Publications Scientifiques et Techniques du Ministère de l'Air

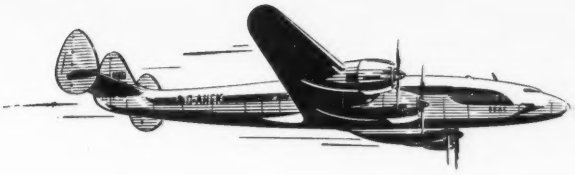
228—*La recherche du nuage radioactif. H. Garrigue.*

229—*Anisotropie, symétrie, hétérogénéité en élasticité. A. Brodeau.*

230—*Les mesures de température dans la technique des moteurs d'aviation. P. Vernotte.*

J. LAURENCE PRITCHARD,
Secretary.

THE LEWES PRESS (Wightman & Co. Ltd.), Friars Walk, Lewes, Sussex



"Every Speedbird Service has *your* name on it!"

Flying by B.O.A.C. I always feel as though the whole trip was planned *especially* for me. The service, the meals (complimentary, of course), the constant concern for my comfort — all combine to make me feel completely at home.

This talent for service with the accent on *you* — a talent learned during 30 consecutive years of Speedbird experience — begins long before you step aboard your plane. It begins with your local B.O.A.C. Appointed Agent. Just tell him where and when you want to go — then leave the details to him. On the day of your flight you'll see this same quiet, efficient Speedbird Service at work in city terminal and airport — answering questions, giving expert advice, checking tickets and handling baggage.

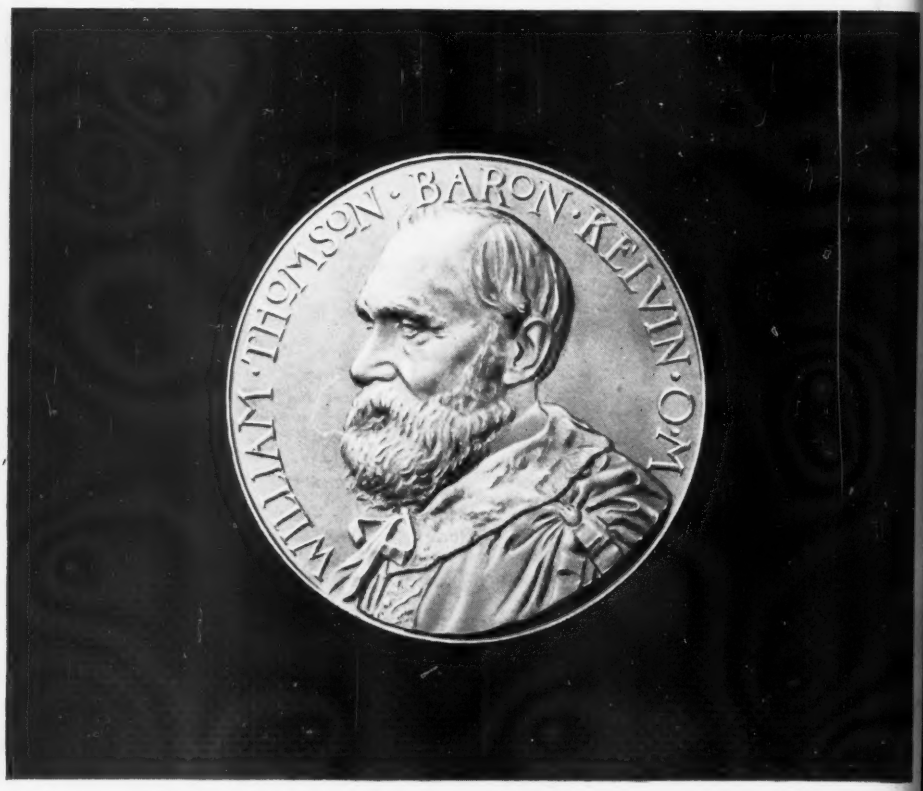
Yes, wherever you may fly along 175,000 miles of B.O.A.C. routes to six continents and fifty-one countries, you will experience this same high standard of efficiency and courtesy. The actual flight is swift, sure and comfortable. No extras, either, for distinctive Speedbird Service that has *your* name on it!

GREAT BRITAIN - USA - BERMUDA - CANADA - WEST INDIES - CENTRAL AND SOUTH AMERICA - MIDDLE EAST WEST AFRICA - EAST AFRICA - SOUTH AFRICA - PAKISTAN INDIA - CEYLON - AUSTRALIA - NEW ZEALAND - FAR EAST - JAPAN

B.O.A.C. TAKES GOOD CARE OF YOU

FLY BY B·O·A·C

BRITISH OVERSEAS AIRWAYS CORPORATION WITH Q.E.A., S.A.A., T.E.A.L.



Towards human progress . . .

One hundred years after the foundation of the firm which bears his name, we more deeply appreciate that one of the greatest of Lord Kelvin's achievements was his bridging of the gap between academic theory and engineering practice, his application of scientific principles to human affairs. To commemorate this, the Kelvin Gold Medal is awarded triennially as a mark of distinction in engineering work or investigation of the kinds with which Lord Kelvin was identified. When the latest award was made in 1947 to Air Commodore Sir Frank Whittle, he was spoken of by Sir John Anderson as one of those men whose 'contribution to human progress is incalculable.'

KELVIN AIRCRAFT INSTRUMENTS

PROVEN IN RELIABILITY — AHEAD IN DESIGN KBB

KELVIN BOTTOMLEY AND BAIRD LIMITED · BASINGSTOKE

Printed by the LEWES PRESS (Wightman & Co. Ltd.), Friars Walk, Lewes, England, and Published by THE ROYAL AERONAUTICAL SOCIETY, 4 Hamilton Place, London, W.1, England.